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ABSTRACT

This guide for elementary Teacher preparation programs in science education comprises three sections: "Introduction"; "Guidelines"; and "Implementation." The reform efforts, particularly those pertaining to science education, are characterized by a shift towards shared responsibility for the preparation of teachers to include collaborative models that involve teachers of science at many levels. In this document the term "teachers of science" represents many levels of teachers from colleges and universities, public schools, centers for professional development, teacher preparation programs, and informal science institutions. The guidelines in this document refer to certain characteristics of learning environments that strengthen the preparation of elementary teachers, which include collaboratively designed and implemented program support; a hands-on, problem-solving environment in which to learn; instruction that puts the student at the center of the process; focusing on scientific inquiry as the core of all levels of science teaching and learning; and regarding professional growth in science teaching as a continuous and collaborative process. Contains 85 references. (DDR)

Elementary Teachers Do Science

Guidelines for Teacher Preparation Programs

Carol L. Stuessy & Julie A. Thomas

ERIC Clearinghouse for Science, Mathematics, and Environmental Education

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- A vita and a writing sample.

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Texas SSI Action Team
on
Strengthening the Science Preparation of
Elementary Teachers

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The diverse group of preK-16 science educators was commissioned by the Texas Statewide Systemic Initiative to develop a set of guidelines to strengthen the science preparation of elementary teachers. This document was written under their direction. Carol L. Stuessy (Texas A&M University) and Julie A. Thomas (Texas Tech University) prepared the final version. This document was made possible with funding from the National Science Foundation. For more information contact (512) 471-6191.

Preface

Science literacy for all students has become an established goal in standards-based movements that are occurring in almost all of the states in the nation. The *National Science Education Standards* reflect this goal, expressing the notion that science enables everyone to share in the richness and excitement of understanding the natural world. Science literate individuals possess the knowledge and skills to solve problems, make decisions, and be lifelong learners as they live, work, and learn in a society driven by and dependent on emerging technologies. In Texas, new science educaion standards in kindergarten through twelfth grade were adopted by the State Board of Education in July 1997 as the *Texas Essential Knowledge and Skills in Science* (*TEKS*).

Like the *National Science Education Standards*, the new science *TEKS* reflect a change in emphasis. Curriculum standards based on goals of scientific literacy are very different from the traditional curricula that were designed to train scientists and the academically elite. The *TEKS* present science as "science for all," knowledge and skills useful and meaningful in everyday life in light of problems to solve and decisions to make. The new *TEKS* also reflect many of the significant changes in the scientific enterprise that have occurred in the last quarter of this century. Modern science has replaced the old boundaries of traditionally structured disciplines with new hybridized content areas and identifying labels, such as engineering physics, biochemistry, astrophysics, and biotechnology. Research paradigms have also changed, including increased dependency on collaboration and computers, and increased attention to solving social problems. Science, society, and technology are seamlessly positioned at the center of modern society. Science literate individuals possess more than scientific knowledge; they recognize and understand the impact of the scientific enterprise on all aspects of our society, our economy, and our lives.

Science literacy begins with the very young, in the elementary grades, when curiosity and needs-to-know are fresh and demanding. When these needs are met, elementary school science sets the stage for continued successful learning, positive impressions about science, and informed career choices. Responsible practice in preparing elementary school children to be science literate is essential in building children's foundations for later science experiences and interactions.

The call for reform in improving what goes on in schools began in the early 1960's and 1970's with more attention to "systemic change" having occurred in the 1990's (see Office of Educational Research and Improvement, 1996; National Science Foundation, 1997). "Changes must take root in every community and must reach the great majority of students" (National Science Foundation, 1977, p. 4). Until recently, teacher preparation has been the critical piece of the education reform agenda that has been missing. It was missing from the 1983 report, *A Nation at Risk* (National Commission on Excellence in Education, 1983), which alerted the nation to the failing condition of our schools, from the call in 1989 by

President Bush and the Nation's governors for National Education Goals, and from the tidal wave of activity that has produced standards in all the key curriculum areas (Stoehl, 1997).

Science education has been no exception. Teacher preparation was not highlighted in earlier state or national science documents, such as *the Science Framework for California Public Schools* (California State Board of Education, 1990), when the authors recommended that "teachers stand solidly behind efforts ... to raise standards for teaching in every field; and call upon those groups to use the recommendations of this report in establishing standards for science and mathematics teachers" (p. 165). The *National Science Education Standards* (National Research Council, 1996) mentioned science teacher preparation made in reference to continuous professional development.

> The following standards...are not divided into standards for the education of prospective teachers and standards for the professional development of practicing teachers. Rather they are applicable to all activities and programs that occur over a teacher's career. (p. 57)

Since 1993, science teacher preparation has focused the attention of a number of "non-standards-writing" groups including the National Science Foundation (1993, 1996), the National Science Teachers Association (Glass, Aiuto, & Andersen, 1993), and the National Center for Improving Science Education (Hawkins & Michelsohn, 1995). The National Science Foundation reported in the spring of 1996 that only about two-thirds of teachers of grades 1 through 8 have completed at least one college course in the biological, physical, or earth sciences. Less than 30 percent of elementary school teachers said that they felt well qualified to teach science, compared to 60 percent who felt well qualified to teach mathematics, and close to 80 percent who felt well qualified to teach reading. Furthermore, many elementary school teachers continue to have an incomplete view of science, seeing it as a body of textbook-based information that the scientific community has developed and that students need to learn. Teachers have not learned science in a way that has enhanced their own science literacy. Their science learning did not reflect a view of science as a way of understanding the world that uses certain modes of inquiry, rules of evidence, and ways of formulating research questions. Elementary teachers most often view science as a subject to be learned as it was taught to them: by didactic methods that reinforce the notion of science as an inert body of knowledge.

Achieving science literacy for the children of Texas begins with achieving science literacy for Texas' prospective teachers, who are currently coming to colleges and universities underprepared in science. Teacher education programs that strengthen the science literacy of prospective teachers begin professional development in science during the early years of their undergraduate preparation when there are opportunities for prospective teachers to engage in science as active learners. Programs that promote science literacy also provide opportunities for prospective teachers to gain some preliminary experience in teaching science in the elementary schools, also. New teachers then have a richer experiential base in science teaching to connect to the realities of the first years in the classroom. They grow by working collaboratively with other teachers, taking advantage of professional development opportunities, and learning from their own efforts and those of their colleagues.

Traditional models place the responsibility for preparing preservice teachers primarily with colleges and universities. New models of teacher preparations, however, engage the public schools at early stages in the preservice teachers' preparation instead of waiting until the end of the program when student teaching traditionally occurs. Continuous professional development with a gradual shift from campus to school is recommended. Collaboration, corroboration, and responsible practice among colleges, universities, and public schools are required for a successful program of integrated preparation.

Where is Texas in the process of reconceptualizing elementary teachers' preparation in science? The Texas Statewide Systemic Initiative for Mathematics and Science (Texas SSI) was funded by the National Science Foundation in the fall of 1994. The Texas SSI adopted an interactive, interdependent model for reform in science and mathematics education that currently includes nine action teams working within the Texas SSI framework. One of the original Texas SSI action teams was the Preservice Elementary Science Preparation Action Team, formed to directly address the need of strengthening the science preparation of Texas elementary school teachers. Texas is one of several state systemic initiatives that has focused on the preparation of elementary teachers as a critical element in achieving science literacy for children. Approximately 85,000 classroom teachers currently teach in the 3,757 public elementary schools in the state of Texas. With these numbers in mind, the preparation of elementary teachers was considered to offer more potential and promise as a starting point in tackling the complex issues associated with changing the way science is taught and perceived in the elementary schools of Texas. This approach focused the attention of the action team directly on those most responsible for the science preparation of elementary teachers: colleges, universities, and public schools.

The action team on preservice elementary science preparation has not limited its vision exclusively to the preservice arena. Knowledge of new collaborative models of teacher preparation has expanded the vision to include practicing classroom teachers as well. One such model employed in Texas schools is the Center for the Professional Development of Teachers (CPDT), modeled after national efforts to form school-based Professional Development Schools (PDS), which also exist in Texas. In these models, universities and public schools engage in collaborative problem solving to meet the needs of both prospective and practicing teachers in a manner that deals with rapid changes in society and in the scientific enterprise. Professional development of teachers begins in the undergraduate years but continues throughout the lifetime of the elementary school teacher. As science, society, and technology continue to advance, attention to the needs of elementary teachers also continues to grow among those who share the responsibilities for educating the nation's children.

The guidelines that constitute this document provide a new vision of science preparation for elementary teachers, following the current wave of reform in response to new needs and pressures for education. Significant in this wave is the shift towards shared responsibility for the preparation of teachers, to include collaborative models that involve teachers of science at many levels. In this document, the term *teachers of science* is therefore used intentionally and consistently to represent the many levels of teachers of science in

colleges and universities, public schools, centers for professional development, teacher preparation programs, and informal science institutions.

These *Guidelines*, therefore, were written in recognition that all teachers of science will be the community of scholars who ultimately will be responsible for strengthening the science preparation of elementary teachers. The *Guidelines* state that the science preparation of elementary school teachers is strengthened within learning environments where

- All teachers of science are supported by a program that is designed, integrated, implemented, and assessed collaboratively by a diversity of stakeholders.
- All teachers of science learn the content and process of science through experiences that extend their integrative powers in problem solving and support their active pursuit of answers to questions about the natural and designed world.
- All teachers of science deliver science content knowledge in a way that positions the student at the center of the teaching and learning process.
- Scientific inquiry forms the core of science teaching and learning experiences for students at all levels.
- Professional growth in science teaching is a continuous and collaborative process that begins during undergraduate preparation and extends throughout the professional careers of all teachers of science.

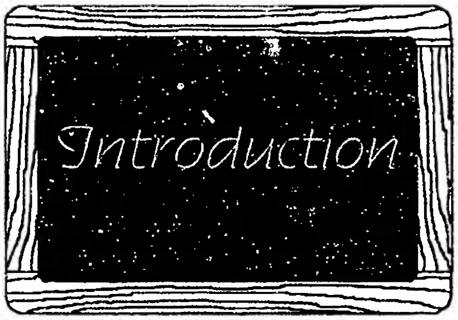
Audience

The *Guidelines* were written with the three groups most responsible for the preparation of elementary school teachers in mind. These groups include (1) college and university science faculty members, (2) college and university education faculty members, and (3) public school teachers and administrators. These groups traditionally provide instruction in science courses, in science methods, and in clinical experiences, respectively. New models of teacher preparation engage all three groups in sharing the responsibilities for designing and implementing programs. Although this document has been written for educators in the state of Texas, we believe that the recommendations that follow will be helpful to other groups interested in strengthening the science preparation of elementary school teachers.

Organization and Content

This document comprises three sections: Introduction, Guidelines, and Implementation. The Introduction provides an explanation of the Preservice Elementary Science Action Team's model for preservice elementary science preparation. Details regarding process, format, and information sources contributing to the document are also described. The Guidelines section presents five guidelines, each of which begins with a general statement and bulleted descriptive statements that directly follow. An annotated text supports each of the bulleted statements with explanatory information: text boxes contain illustrative statements and descriptions from representatives of the stakeholders who are ultimately responsible for the science preparation of elementary teachers. The Guidelines section also provides for each guideline a list of Questions to Consider to stimulate further discussion during the processes of problem definition and solution associated with

restructuring preservice elementary science preparation programs. The final section, Implementation, gives guidance to those individuals considering the implementation of the Guidelines, with some specific examples from implementation efforts in Texas institutions that are currently under way to strengthen the science preparation of preservice teachers.



A Systems Model for Restructuring Elementary Science Preparation Programs

> The problems we face in reforming math and science education are so complex, interdependent, and interwoven, they can only be addressed through broadly based collaboration between universities and the schools. We must stop finger pointing and begin bridge building. Higher education needs to listen to...K-12 and vice versa. We need to expand the number of statewide coalitions and summer workshops for science and mathematics teachers, we need to revamp teacher preparation programs, we need to develop faculty/teacher exchange programs between schools and universities, and we need on-campus experiences for students of all ages.[1]

A Case Study in the National Interest

This document is the result of serious efforts to reform science education through statewide collaboration and the building of bridges between universities and K-12 schools. Though the guidelines presented here have emerged in the context of systemic reform of science and mathematics education in Texas, they have national import. Such guidelines are needed for science teacher preparation programs thoughout the nation, and a broad-based process of collaboration will be essential wherever systemic, continuous reform in science education takes hold. Both the guidelines and the development process presented here are offered in the spirit of collaboration; we must learn from each other's efforts if we wish to build strong bridges among teachers of science at all educational levels. These guidelines were developed with national standards in mind from consideration of the collective wisdom of science educators worldwide. Though the guidelines are tailored to the specific needs of science educators in Texas, they reflect the national and worldwide standards for professional growth and reform in science education.

The Process of Science Education Reform in Texas

The National Science Foundation funded the Texas Statewide Systemic Initiative (Texas SSI) in Mathematics and Science in the fall of 1994. One of the major tasks of the Texas SSI

was to provide guidance in restructuring the science preparation of elementary teachers in the state. The Preservice Elementary Science Action Team was formed in the summer of 1995 to address the task by writing a set of guidelines that would be consistent with the goals of elementary school science teacher preparation in Texas.

> The goal of elementary science teacher preparation in Texas is to optimize learning and maximize opportunities for all learners. Diverse resources of people, cultures, history, technology, and community enhance science literacy. Elementary school science provides teachers and their students with the knowledge and skills to be lifelong learners, productive citizens, creative problem solvers, and informed decision makers.[2]

Texas is a demographically complex state characterized by highly legislated and regulated control of the public education of children all the way from small, isolated rural communities to huge, rapidly developing metroplexes. The Texas SSI adopted the interactive, interdependent action team model to build capacity for change in mathematics and science education with the state. Collectively, the Texas SSI action teams constitute a decentralized model for effecting statewide change, serving as venues for reaching consensus, establishing communication networks, and influencing practice at the level of the classroom.[3] The Preservice Elementary Science Action Team is one of several now operating in the state of Texas under the umbrella of the Texas SSI.

Although the efforts of the Texas SSI action teams have been occurring simultaneously, two in particular are germane to the *Guidelines* presented in this document: the Preservice Elementary Science Preparation (PESP) Action Team and the *Texas Essential Knowledge and Skills* (*TEKS*) Action Team. The latter has been directed to develop the newly mandated state standards in science education. The *TEKS* were adopted by the State Board of Education in July 1997 and will ultimately guide decision making regarding curriculum at the district level and assessment at the state level. The *TEKS* will also guide colleges and universities in restructuring their entrance requirements, program designs, and science content and curriculum for courses that prepare elementary teachers to teach science. The *TEKS* Action Team was the largest of the Texas SSI teams, with 36 members representing teachers, science supervisors, community college and university instructors in science and pedagogy, parents, and state board of education members—all stakeholders working on the common goal of improving the quality of science education in the state.

The Preservice Elementary Science Action Team

Members who served on the Preservice Elementary Science Preparation (PESP) Action Team were chosen because of their expertise and experience in a diversity of elementary science

education settings. The team was comprised of eight college and university representatives, including a physical scientist, geologist, educational statistician, two science methods instructors, and three community college representatives; seven teachers (three of whom are Texas Elementary Science Presidential Awardees), including one kindergarten teacher, three elementary teachers, three former teachers who are not graduate students working on Ph.D.'s in science education, and one induction-year teacher; two public school science supervisors, both from urban, predominantly Hispanic school districts; and an education service center from one of the twenty regional service centers in the state. The action team represented the geography and demographics of the state of Texas, spanning the far reaches of the state from El Paso to Houston and Brownsville to Lubbock and the sparsely populated open spaces of Odessa, Canyon, and Caldwell, as well as the sub-tropical, predominantly agricultural Rio Grande Valley at the southernmost tip of the state. (See Figure 1). This group of science educators led the Texas SSI in reconceptualizing the science preparation of elementary teachers in the state of Texas. Three tasks, which are described below, were established by the action team to assist the Texas SSI in restructuring elementary science preparation.

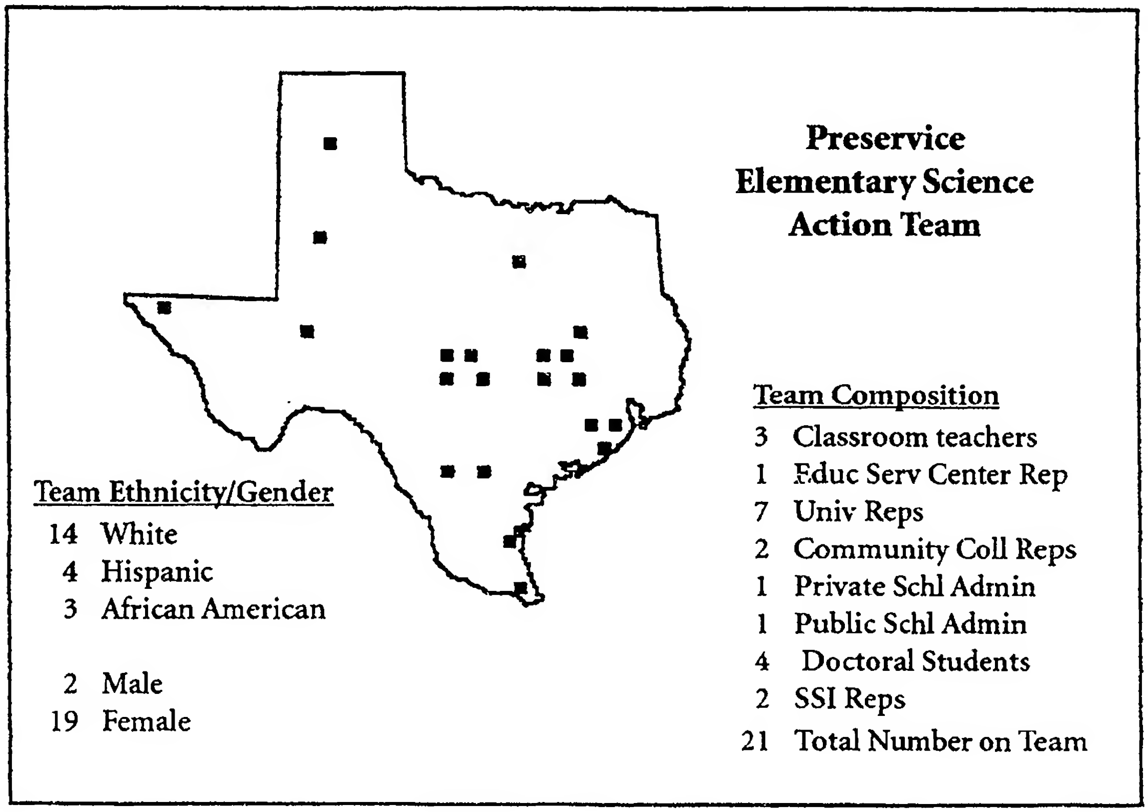


Figure 1 *Preservice Action Team Members represent the diversity and geography of the state of Texas.*

Task One: Development of Guidelines for Restructuring the Science Preparation of Elementary Teachers

The first task of the action team was to develop guidelines to complement the standards-based movement occurring in Texas. The guidelines would specifically address the science needs of prospective elementary teachers in Texas, including the content and structure of ideal science courses and experiences for the preparation, induction, and professional years of the elementary school teacher.

Work on the guidelines document began in the fall of 1995 with the first action team meeting. At that meeting, characteristics of the ideal science preparation program for elementary teachers were generated by individual team members during a brainstorming session. Characteristics of the ideal were written on note cards which were then clustered into categories and labeled. In the second meeting of the action team, each of the categories was reviewed. The action team worked in subgroups to describe each of the categories, using the original note cards to capture the essence of the category. These descriptions were then handed over to a subgroup of six action team members who had agreed to be writers of the first draft of the document. Individual writing assignments were made so that each writer received one category (later called a guideline) to write. Each writer matched the action team's recommendations against those of national documents, including those published by the American Association for the Advancement of Science, the National Center for Improving Science Education, the National Research Council, the National Science Foundation, and the National Science Teachers Association. Individual writing time interspersed with three weekend sessions of the entire writing group completed the first draft, which was presented at an action team meeting in the spring of 1996 for review and subsequent editing. An iterative process of focused writing and intense revision over the course of the next six months led to a first draft of the document which was ready for review in the fall of 1996. Reviewers included a number of state-level focus groups representing the major stakeholders in preservice elementary science preparation: college and university instructors in science and in education, and public school personnel, including teachers, science supervisors, and principals. A formal review by state and national science educators who specialize in elementary science education was completed in September 1997. The document presented here, therefore, reflects a year-long effort of the action team to build capacity and consensus for the guidelines through the review process.

Task Two: Describing the State-of-the-State in Texas for the Science Preparation of Elementary Teachers

A second effort of the action team involved research that led to information regarding the current state of preparation, course work, and classroom practices of science teachers as

Table 1
Research Activities Associated with The Preservice Elementary Science Action Team

Activity	Title	Author/Lead Person
Project 1	Preservice Elementary Science Survey	Dawn Parker Texas A&M University
Project 2	Interviews of Elementary Science Presidential Awardees	Andrea Foster Texas A&M University
Project 3	Telephone Interviews of Randomly Selected Elementary Teachers	J. McNamara & C. Stuessy Texas A&M Research Team
Dissertation 1 August 1997	Collaborative Models for Preservice Elementary Science Preparation at Colleges and Universities in Texas	Dawn R. Parker Texas A&M University
Dissertation 2 May 1998	Teaching Science with Science Eyes: A Study of an Exemplary Elemenatary Science Teacher	Andrea Foster Texas A&M University

they existed in Texas at the time that the Guidelines were written. Three research projects were undertaken, using three different methods to collect data from three different sources. First, a written survey was used to collect data from institutions that prepare and/or certify elementary teachers in the state (see Table 1). Second, in-depth interviews were conducted to collect data from Presidential Elementary Science Awardees regarding their classroom practices and perspectives. Finally, a representative poll of elementary classroom teachers was conducted by using the method of probability proportionate to size (PPS) sampling to acquire information regarding their classroom practices and perspectives. Three separate reports of the research were prepared by the action team, and two doctoral dissertations were derived from the work of the team (see Table 1).

These data were also used to establish priorities for the final year of support by the National Science Foundation for Systemic reform in elementary science preparation. The model adopted for establishing statewide priorities was similar to that used in Project Synthesis (1980) and later in the Accelerated Schools training model (1996). The model required the comparison of the ideal, or desired, state to the real state of the program. The comparison led to the establishment of priorities that reflected the differences in ideal and real states. The data from three research projects, which assessed the current state of preparation and practices in elementary science teaching, were used to compare the ideal as reflected in the Guidelines with what was known about the current preparation and practices in elementary science in the state. The

results of the comparison led to the third task of the action team, which was to establish priorities for seed grants and implementation grants which were funded for the summer of 1997 and January through August of 1998, respectively.

Task Three: Implementing the Guidelines

With the completion of the *Guidelines* and their related research projects, Requests for Proposals were developed in the spring of 1997 to encourage preservice preparation programs to seek funding for restructuring the science preparation of their elementary preservice teachers. Small summer planning grants and larger implementation grants were rewarded to collaborative partnerships comprised of diverse members who have chosen to restructure their preservice elementary science preparation programs. These partnerships were formed from institutions across the state, with collaborators including members from public schools, community colleges, comprehensive four-year colleges, research universities, and informal science institutions.

Planning projects and implementation projects have revealed surprising flexibility in accommodating the guidelines. Multiple solutions have been designed for the problems of restructuring preservice preparation at the home institutions of the collaboratives. Planning projects, which focused primarily on networking and professional development activities to enable partners to assume new roles and responsibilities in preservice preparation, were creative and successful in producing fundable implementation proposals. Implementation projects have incorporated a number of innovative strategies, including the design of summer museum experiences for preservice and inservice teachers, the restructuring of existing science content courses, the development of new courses at community colleges for preservice teachers in science pedagogy and in science content, the development of a school-based, after-school academy in which preservice teachers work with students in investigations on science topics, and intensive field-based summer science courses for prospective and practicing elementary teachers. Common to all projects has been the commitment by all partners to address the guidelines. Innovative strategies reflect the strengths and special challenges of the partners, as well as the unique demographic characteristics of the collaborative.

A Systems Model for Restructuring Programs

The Road Map to Restructured Programs in Elementary Science Preparation (see Figure 2) reflects the activities and time line of the tasks associated with the Preservice Elementary Science Action Team, beginning with the formation of the team in the fall of 1995 and continuing with the development of guidelines, supervision of research projects, and establishment of priorities for planning and implementing new models of preservice preparation.

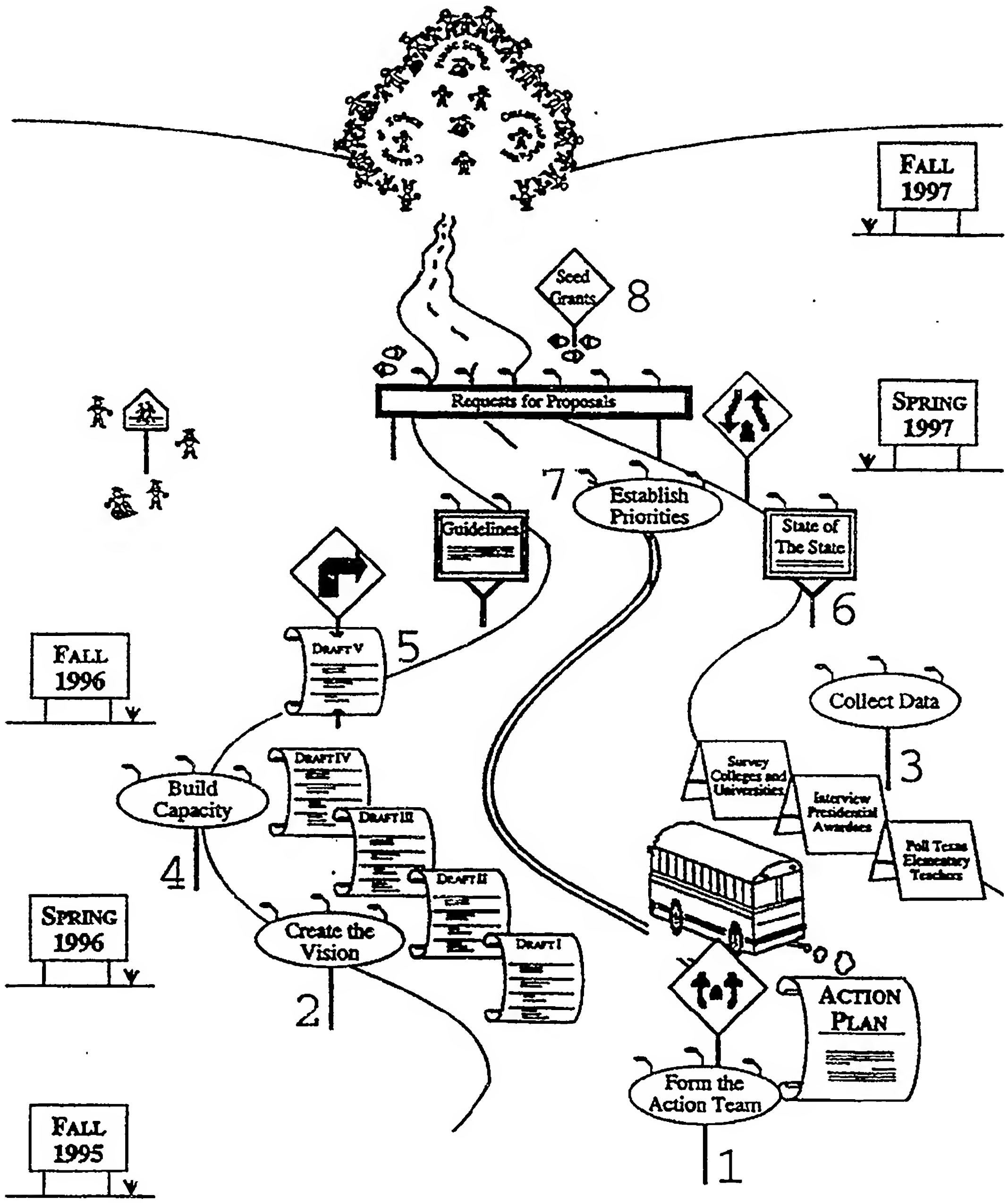


Figure 2 *The Roadmap to Restructured Programs in Elementary Science Programs reflects the timeline of the action team, beginning with its formation in the fall of 1995 and continuing with the development of the guidelines and establishment of priorities for strengthening the science preparation of elementary teachers.*

Key Players

In the context of the work of the action team, the first major decision was to define teachers of science as all teachers of science who represent colleges and universities, public schools, teacher preparation programs, and informal science communities. *Faculty*, whether tenured, tenure-track, adjunct, or graduate student, refers to personnel who teach science or science methods courses for preservice teachers. *Classroom teachers* refers to teachers in the pre K-12 schools, with the further distinction that *induction-year teachers* are in their first or second year of teaching. The term *preservice teachers* refers to students in higher education who are seeking elementary teacher certification. *Students* refers specifically to elementary classroom students. Institutions refers to institutions of higher education—public and private, two- and four-year, who knowingly or unknowingly prepare elementary teachers. *Schools* refers to public pre K-12 buildings and systems. *Stakeholders* refers to all individuals who have a stake in science literacy, including the many types of individuals who play a critical role in improving science education: teachers; science supervisors; curriculum developers; publishers; those who work in museums, zoos, and science centers; science educators; scientists and engineers; school administrators; school board members; parents; members of business and industry, and legislators and other public officials.[4]

Challenges

Educational change occurs in environments of considerable diversity. There are enormous differences among universities and colleges, school districts and schools within them, and individual teachers and instructors teaching one particular content area or age group. There can be extreme differences among elements within any educational system or subsystem. Teachers responsible for teaching science in one public school building, for example, may exhibit large variations in their areas of expertise in subject-matter knowledge, pedagogical skills, and philosophy of education.[5] The same is just as true with science faculty members, who also exhibit large variations not only in their areas of teaching expertise but also in other professional priorities such as tenure, service, research, and scholarly productivity.

There is also great variability in the barriers faced by individual teachers of science and by their schools and institutions. Public schools experience pressures and priorities that may have little in common with institutions of higher learning; restricted human and financial resources, dropout rates and increasing needs of diverse learners, and accountability through state-mandated testing. (Currently in the state of Texas, for instance, state-mandated testing in reading and mathematics has led many building administrators to restrict teachers to "teaching to the test." Many teachers across the state testify that science is not taught in the elementary

classroom because it is not tested.) Other very different pressures and priorities exist for faculty in situations of higher learning, which often reward research productivity at the cost of excellence in teaching, particularly at the undergraduate level.[6]

Any educational reform is an evolutionary change in teaching that occurs within a system functioning as a whole due to the interdependence of its parts. Although there are many components within the school system, teachers are the most critical ones.[7] The system of bringing responsible practice to bear in science education in Texas requires the involvement of all teachers of science. The interdependence among university and public-school-based science teachers has never been more necessary. The magnitude and difficulty of the changes in science education reform, most readily seen in the new *Texas Essential Knowledge and Skills in Science*, rest with all teachers of science in the state. Teachers of science at all levels bear the ultimate responsibility for implementing science reform.[8]

Restructuring programs in elementary science preparation presents a formidable challenge. As new goals of science teaching are embraced by teachers of science at one level, effects are felt by other teachers of science. Change in any one component of the system has direct effects on the other components, whether the changes occur first with teachers of science at the university level, experienced classroom teachers, newly inducted classroom teachers, or preservice teachers enrolled in preparation programs. To use Rodger Bybee's evolution analogy, the challenges these groups experience are the "environmental contingencies"[9] of successful adaptation.

Underrepresentation in Science

Current reform initiatives are challenged to ensure that improved science education reaches all students throughout the system—not just those who typically go on to careers in science and mathematics or those who seem bound for college.[10] In a technologically advanced culture, the scientifically illiterate are disallowed entry into educational, economic, and political arenas.[11] As women and minorities become larger segments of the [Texas] work force, they will be less well represented in the field of science and technology.[12] Elementary teachers are now assuming greater responsibilities for helping females and minorities to succeed in these fields. Researchers such as Carolyn Dweck[13] have confirmed the significant role of elementary teachers in encouraging positive feelings of self-efficacy in science in their students; yet national reports[14] continue to present alarming statistics regarding elementary teachers' own negative feelings towards their abilities to teach science.

The most powerful force in helping all students to achieve is the consistent belief that they can succeed. Teachers can be especially effective in promoting positive attitudes about their students' abilities and achievements. From the start, preservice teachers must learn to

demonstrate their expectations that every child can make significant contributions in science class. Preservice teachers can learn to apply effective strategies to increase the interest, motivation, and achievement in science of females, minority students, and students with disabilities. These strategies include using appropriate role models in science who can translate their personal experiences into significant learning experiences for elementary students; building parent involvement and peer recognition programs to increase interest in and acceptance of science efforts; capitalizing on students' prior knowledge to link new knowledge with what students already know about the natural world; and maintaining the same standards for all students.[15] A spirit of experimentation has emerged among experienced practitioners who are serious about reform.[16] They are applying a wide range of strategies in new forms of assessment, use of hands-on materials, promoting practices in which all students learn together, forging alliances among schools, families, and communities, and holding practitioners and schools accountable for both quality and equity.[17]

It is most important that preservice teachers recognize equity issues and raise their own awareness of equity in science education and throughout the culture of the educational systems in which they will work.[18] Public schools in Texas provide significant yet subtle indicators regarding the expectations of teachers for all children to do well in science. A challenge for an effective teacher is for all children to do well in science; the challenge for an effective teacher preparation program is to provide opportunities for preservice elementary teachers to explore a variety of school cultures and learn how to make relevant connections between in-school science learning and the out-of-school learning that occurs in the lives of children of diverse cultures, backgrounds, and experiences.

Solutions

Figure 3 illustrates the interdependency of all teachers of science reflected in the *Guidelines*. You will notice that the figure models a wheels within wheels process, first described by the Accelerated Schools Program at Stanford University. In restructured programs, individual wheels of colleges and public schools will be replaced by a larger wheel representing a community of university and college instructors, experienced classroom teachers, new teachers, and preservice teachers. The Texas SSI Preservice Elementary Science Action Team is such a wheel, formed at the state level from representatives of community wheels that will eventually strengthen the science preparation of elementary teachers in the state. The action team works together to solve a state-level problem and to also build capacity for reform as its members take new knowledge and experiences back to their local communities. The *Guidelines* prepared in this document provide direction at all levels—community, region, and state—for strengthening the preparation of elementary science teachers.

Changing Emphasis

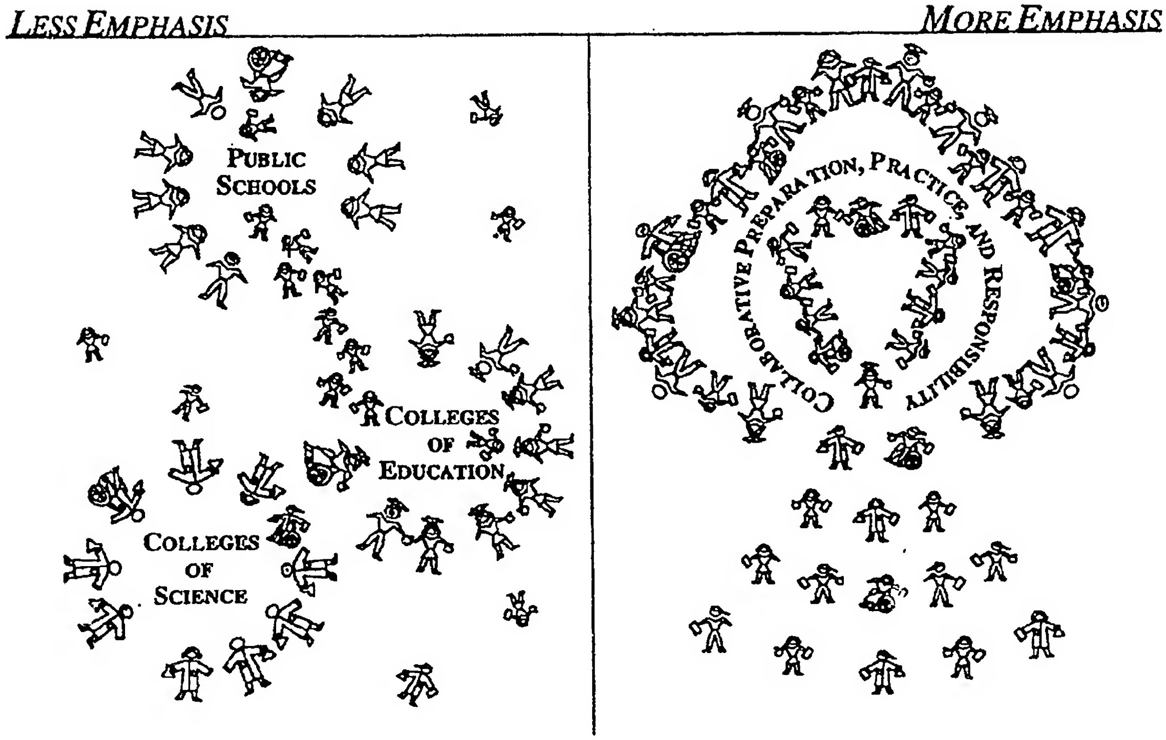


Figure 3 *Changing Emphases in Programs that Prepare Elementary Teachers indicates that individual wheels of colleges and public schools will be replaced by a larger wheel representing a community of university and college instructors, experienced classroom teachers, new teachers, and preservice teachers.*

Continuous Institutional Support

Guideline 1 requires that diverse stakeholders share the responsibility for program design, integration, implementation, and accountability (see Chapter 1). Collaborative decision making and problem solving is a cornerstone of many organizational bodies.[19] Collaboration is a strategy for helping individuals work together to pursue and review their own purposes, where individuals bring to the process their expertise and commitment and share the responsibility and authority for program design and implementation. In the design of programs that prepare Texas elementary teachers to teach science, three organizational bodies are critical: colleges of science, colleges of education, and school communities. Input from each is essential in creating science preparation programs for preservice teachers. Information about priorities and related pressures from each

perspective are just as important in sustaining reform as the expertise and experiences these collaborators can bring to the tasks at hand.

Implementation of the *Guidelines* requires a substantive change in how science is taught; an equally substantive change is needed in professional development activities.[20] William Kirwan stated in a keynote address at a National Science Foundation workshop on the Role of the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers that the difficulty of the nation in effecting meaningful reform in mathematics and science education can be attributed to many factors, including a highly complex educational system comprised of levels, each one depending upon and affecting the levels immediately above and below. He posed a number of questions.

> Where does one start the process of reform? At the preschool level? If so, it could take the better part of two decades for reforms to work their way through the system. At the high school level? How would that be possible if the students entering high school arrive from middle school with present deficiencies? Should we begin at the college level? It is, after all, the colleges and universities that train teachers for the K-12 classroom. Do we start at all levels simultaneously? Such an approach is almost too complex and too expensive to contemplate.[21]

Dr. Kirwan also believes "a strong case can be made for the university as the best place to begin this reform effort. Not only do the universities train the teachers for the K-12 classrooms, it is the universities that provide the final phase of the education for the Nation's technological workforce."[22] He talks about reform of teacher preparation programs within the broader context of reform in all collegiate level science and mathematics education.

> If future teachers are to take more discipline-based courses—as I think they must—then their knowledge of content areas will reflect the quality of undergraduate education offered to all students. We must overhaul the way we teach mathematics and science. We must learn how to engage the students—including future K-12 teachers—as active participants in the learning process.[23]

Raizen and Michelsohn further state that faculty from colleges and universities responsible for delivering science courses must think differently about the science they teach to prospective elementary school teachers. This science is different than that taught to science majors. Courses for prospective elementary school teachers provide a foundation for lifelong, autonomous science learning, as these courses may well be the last formal science education that this group of learners receives. Prospective elementary school teachers must equip themselves to be self learners, and their science courses must include the development of specific strategies to this end. Effective science teachers will develop life-long skills to seek out new information, materials, and strategies.[24]

Change in science teaching requires teachers of science to change their perceptions of themselves as science educators. A common language reflects common understandings. Rodger Bybee asserts that the term science education combines the specific content and processes of science with the general purposes of education.

> Although this may seem a statement of the obvious, science educators have tended to pay more attention to science and less to education in their definition and justification of goals. My discussion centers on education, an orientation that is sometimes recognized but never emphasized in professional discussions. Yet education is, or ought to be, the fundamental orientation of our profession. Science describes the type of education with which we are involved. Concentrating on education clarifies our larger purpose while maintaining the integrity of scientific and technologic content and method.[25]

The guidelines that follow present challenges to all teachers of science. Successful teachers of science in Texas will understand the new content standards of the *Texas Essential Knowledge and Skills in Science* and learn to implement them in their classrooms; they will have contemporary conceptions of the science learner, the learning process, and their implications for instruction, and they will learn how to use and incorporate inquiry-based instruction and assessment strategies for teaching and learning in the science classroom. These are all elements of what Lee Shulman[26] includes as part of the pedagogical science content knowledge that underlies teachers' classroom performance: knowledge about science, knowledge about how science is learned, and knowledge about how the objects in the classroom—textbooks, equipment, and computers—are managed. All this knowledge must be integrated into a coherent whole by each teacher of science. Successful implementation of new programs requires that science teachers learn new ideas and integrate them with their own views of teaching and learning.

Individual efforts of teachers of science can lead to successful implementations of reform in individual classrooms. Reform reaches beyond individual classrooms when teachers of science are supported by the educational communities they represent, which may include institutions of higher education, community colleges, educational service centers, business and industry, and informed science institutions.

Voices Represented in This Document

The Voice of the Texas SSI Preservice Elementary Preparation Team

The *Guidelines* represent the voice of the Preservice Elementary Science Action Team, a state-level wheel formed to examine the current state of preservice elementary science preparation and to make recommendations for strengthening programs. Support for each

guideline comes from the *National Science Education Standards* and other documents supporting reform in science education, including those from the National Science Foundation, National Academy of Sciences, American Association for the Advancement of Science, and National Science Teachers Association.

The Voices of Institutions that Prepare Elementary Teachers

State-of-the-state information in the *Guidelines* provides an overview of where Texas now stands in regard to the specified guideline. This information was chosen from data acquired under the direction of the action team from individuals representing preparation institutions in Texas. More complete information regarding the state-of-the-state, of course, is available in the companion documents prepared by the Texas SSI that represent the current state of science education practices and programs in Texas.

The Voices of Teachers of Science

The voices and perspectives of Texas' teachers of science, including college and university teachers of science, experienced public school teachers of science, induction-year public school teachers of science, and preservice elementary teachers, appear within boxes in the text. These comments provide information about the specified guideline that represents the personal perspective that is critical in reform and which by necessity occurs at the level of the individual.

Without Guideline 1, which may be the most challenging guideline to achieve, all the state of Texas can expect in terms of educational reform in science education are a few individual teachers of science who have been able to persevere in spite of professional isolation, institutional pressures and priorities, and external reward structures that create formidable barriers to significant change in science education at the state level.

Summary

Science for all students necessitates a science education that is no longer structured to train scientists and the academically elite. Changes in emphasis must occur to close the gap between the haves and the have-nots, with better science education recognized as a "requisite for students at all levels of society."[27] Using a format similar to that developed by the National Council for Teachers of Mathematics and the National Research Council, each of the guidelines reflects a change in emphasis, as summarized in Table 2.

The document that follows is comprised of five guidelines corresponding to the original categories of the Preservice Elementary Science Preparation Action Team. These categories are as follows: Collaborative Programs, Science Content and Process, Student-Centered

Table 2
Changing Emphases

The *Guidelines* for strengthening the science preparation of elementary teachers envision change occurring within a system. The *Guidelines* encompass the following standards-based changes in emphasis.

Collaborative Programs

Less Emphasis On	*More Emphasis On*
Teacher education programs directed, controlled, and managed by colleges of education.	Collegial, collaborative programs with responsibilities for teacher education shared by specialists in content, pedagogy, and elementary teaching from public schools, colleges, and universities.

Science Content and Process

Less Emphasis On	*More Emphasis On*
Knowing scientific facts and information studied within subject matter disciplines.	Learning science in relevant contexts that require learners to conduct inquiries and solve problems.

Student-Centered Teaching

Less Emphasis On	*More Emphasis On*
Knowledge about science content taught separately from knowledge about how to teach teach.	Applying knowledge about how students learn with knowledge about science content and teaching science.

Inquiry-Based Teaching And Learning

Less Emphasis On	*More Emphasis On*
Learning science by lecture, reading, and rote strategies.	Learning science by inquiry, producing deep conceptual understandings about science and enhancing scientific thinking skills.
Teaching science by lecture.	Teaching science with an inquiry approach, producing deep understandings about science teaching and enhancing critical teaching skills.

Continuous Growth

Less Emphasis On	*More Emphasis On*
Classroom teachers as those solely responsible for solving problems about teaching elementary science; college and university faculty restricting their teaching focus to science content.	Teachers as public school specialists who join forces with other teachers of science to solve problems regarding the teaching of science to elementary children and to their prospective teachers.
Technical, short-term workshops for teachers who are perceived as the only ones in need of information about how to teach science effectively.	Teams of teachers from public schools, colleges, and universities implementing continuous, prolonged learning experiences that enhance the science teaching of all teachers of science.

See the *National Science Education Standards* for more information regarding the changing emphasis recommended in implementing standards-based science programs.

Teaching, Inquiry-Based Teaching and Learning, and Continuous Growth. Each of the guidelines envisions change occurring within a system of professionals and institutions that include institutions of higher education and public schools in equal partnership as well as all the other stakeholders who have a stake in science literacy. These include those who play direct roles in improving science education as well as the many individuals in family, community, business and industrial settings who have the capacity to influence attitudes about the value of scientific literacy in a society driven and governed by the enterprises of science and technology.

Questions to Consider

1. What are the best ways to increase participation of underrepresented groups in elementary school preparation programs?

2. How can all teachers of science be prepared to support students with different needs, preparations, and backgrounds?

3. How can these Guidelines be used to initiate conversations between traditional policy-making groups such as the University Interscholastic League, Higher Education Coordinating Board, and State Board of Education?

League, Higher Education Coordinating Board, and State Board of Education?

Endnotes

[1]William E. Kirwan, "Keynote Address: Role of Faculty in the Disciplines in Undergraduate Education of Future Teachers," *Proceedings of the National Science Foundation Workshop on The Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers* (Washington: NSF, Aug. 1993) 20.

[2]Texas SSI Preservice Elementary Science Action Team, Goal of Elementary Science Teacher Preparation, Action Team Minutes, 16 Feb. 1996.

[3]Uri Treisman, *Mid-Point Report: Texas Statewide Systemic Initiative, report prepared for the National Science Foundation* (Austin: Charles A. Dana Center, Dec. 1995) 3.

[4]National Science Foundation, *Foundations: The Challenge and Promise of K-8 Science Education Reform* (Washington: NSF, 1977) *ix*.

[5]Bybee, *Reforming Science Education: Social Perspectives and Personal Reflections* (New York: Teachers College Press, 1993) 115-6.

[6]Kirwan 19.

[7]Bybee 113.

[8]Bybee 150.

[9]Bybee 108-9.

[10]*Foundations* 84.

[11]California State Board of Education, *Science Framework for California Public Schools Kindergarten through Grade Twelve* (Sacramento: Author) 167.

[12]*California Science Framework* 167.

[13]Dweck, Carol S. "Motivational Processes Affecting Learning," *American Psychologist* 41.10 (1986).

[14]Bybee, National Science Foundation, *The Learning Curve* (Washington: NSF, 1996) (Washington: NSF, 1997); *Foundations* 84.

[15]*California Science Framework* 167-169.

[16]*Foundations* 84.

[17]*Foundations*.

[18]*Foundations* 82-83.

[19]A. Hargreaves and M. Fullan Understanding Teacher Development (London: Cassell, 1991) 17.

[20]National Research Council, *National Science Education Standards* (Washington: National Academy Press, 1996) 56.

[21]Kirwan 18.

[22]Kirwan 18.

[23]Kirwan 18, 20.

[24]Senta A. Raizen and Arie M. Michelsohn, *The Future of Science in Elementary Schools: Educating Prospective Teachers* (San Francisco: Jossey-Bass, 1993) 63.

[25]Bybee 89.

[26]Lee Shulman, "Those Who Understand: Knowledge Growth in Teaching," *Educational Research* 15.2 (1986): 4.

[27]*Foundations* 4.

Collaborative Programs

All teachers of science are supported by a program that is designed, integrated, implemented, and assessed collaboratively by a diversity of stakeholders.

This happens when

- Collaborative programs place primary responsibility for program development and implementation with the faculty from the disciplines of science, faculty from the disciplines of education, and experienced elementary teachers, supported by members of the informal science community and other community stakeholders.
- Collaborative programs recognize and respect the unique perspectives of those responsible for program development.
- Collaborative programs are assessed by a variety of stakeholders.
- Collaborative programs include professional development as an integral part of improving program design.

On Collaboration

> When we give up the illusion that the world is created of separate, unrelated forces, we can then guide *learning organizations* — organizations where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together.[1]

A body of research is developing in the field of education as institutions and agencies engage in working relationships in a variety of modes and for various purposes.[2] While there is little question about the need for or value of collaboration—whether among agencies, organizations, or educational institutions—there is little agreement as to what counts as collaboration.[3] Hoyt has contrasted collaboration with cooperation and defined the two terms in the following way:

> *Collaboration* implies the parties involved share responsibility and authority for basic policy decision making.
>
> *Cooperation* assumes two or more parties, each with separate and autonomous programs, agreeing to work together in making all such programs more successful.[4]

Cooperation and collaboration are different operational processes. They are both valued models. However, each serves a unique purpose, requires certain kinds of input, and yields different outcomes.[5] The following analogy elaborates further on the difference between cooperation and collaboration.

> A mother cooperates with her son by allowing and encouraging his rock band to practice in their home; the son cooperates with the mother by preparing hors d'oeuvres for the mother's guests. These effects are cooperative; the activities are mutually agreeable but not for mutual benefit. The family collaborates in preparing a family meal; they each offer some form of expertise that is rewarding to all [which] contributes to the well-being of the whole group.[6]

Just as collaboration is proposed as a flexible solution to rapid change in business corporations and other organizations, it is also widely proposed as an organizational solution to the improvement of contemporary schooling. Collaborative decision making and problem solving form the cornerstone of many organizations.[7] Collaboration can be a device to help individuals work together to pursue and review their own purposes as a professional community, or it can be a way of reinscribing administrative control within persuasive and pervasive discourses of collaboration and partnership. Collaboration, in this sense, can be a burden as well as a blessing, especially once key stakeholders take over and convert the collaboration into models, mandates, and measurable profiles of growth and implementation. Key stakeholders in collaborative efforts too often prefer to substitute the safe simulation of what is referred to as *contrived collegiality*. This is more harmonious and more controlled than the reality of collaboration itself.[8]

For the purpose of this document, *collaborative partnerships* refers to relationships among those involved in the process of preservice science education. The term *collaboration* is used to extend beyond the cooperation and coordination that generally occurs among education departments, science departments, and school districts due to state classroom observation and student teaching requirements. In creating the types of learning organizations essential to preservice preparation program reform faculties of science, faculties of education, experienced teachers, and preservice teachers bring to the process individual expertise yet share the responsibility and authority for program design and implementation. Relationships are based on a true commitment to improve preservice elementary preparation and prepare exemplary elementary teachers of science.

- **Collaborative programs place primary responsibility for program development and implementation with the faculty from the disciplines of science, faculty from the discipline of education, and experienced elementary teachers, supported by members of the informal science community and other community stakeholders.**

Educational reform of preservice elementary teacher preparation is a shared responsibility. Collaborative partnerships among members of all stakeholder groups, including universities, two-year colleges, public schools, informal science institutions, parents, and businesses, are essential and beneficial to the development of future teachers of science.[9,10] Although the problem of adequate science preparation of elementary teachers has been identified in many reform documents, there continues to be a need for preservice teachers to bolster their understanding of science content and process, as well as the nature of the scientific enterprise. Effective preservice elementary preparation programs are developed and implemented by individuals committed to collaboration built on mutual need and mutual satisfaction, plus realistic expectations. These are integral to program design, integration, and implementation.[11]

This type of commitment means sharing ideas and resources with others who are addressing many of the same problems. In the context of science education, this applies to the scientific community in the degree to which it hopes to make significant contributions to reform in education. The scientific community must enter into a partnership with the education community.[13] For these collaborations to truly work, the relationships must be based on a real commitment of all participants to prepare future elementary teachers of science.[14]

One-fourth grade teacher expressed her thoughts about how a collaborative should work. Her students attend weekly science classes at a museum that are taught by supervised preservice elementary methods students from a local university.

Everybody involved in the program needs to have the same goals they want to achieve. If faculty want to achieve one thing with their students, and classroom teachers want to achieve another thing, and the students want another thing, you are working against one another. Everybody involved in the planning and everything that is planned need to be for the same goals.[12]

Results from the Texas Survey indicated a communication link between science and education departments at 57 percent of the colleges and universities across the state. Eleven percent perceived that there was no communication between departments, and 2% were unsure of the communication existing between departments. There was a "no response" rate of 10 percent for this question. This question was not applicable to 20 percent of the institutions since these institutions did not have both a science and an education department (Figure 4).

Respondents indicating a communication link between departments were asked to describe this communication. Responses fell into three general categories: (1) committee meetings, advisory groups, or councils (36%), (2) "talking" or informal discussions (36%), and (3) planning courses or determining curriculum (28%). Other than the mention of periodic meetings, none of the responses indicated a sustaining communication between departments.[15]

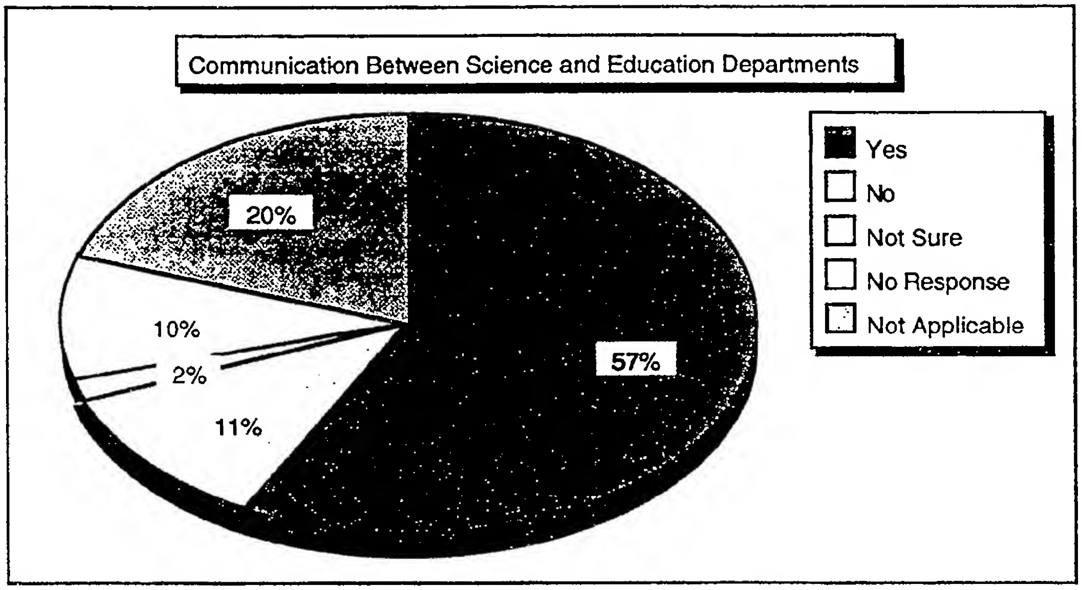


Figure 4. Percentage of Institutional Responses (n=61)
Is there communication between the science department and the education department at your institution?

Results from the Texas Survey also indicated that 57 percent of the respondents said that there was no input provided by school districts or region service centers at their institutions while 27% of the respondents indicated that there was some type of input provided to their institution regarding science course content. Nine percent of the respondents were not sure of the input received from regional service centers at their institution. The remaining 7 percent did not respond to the question (Figure 5).[16]

- **Collaborative programs recognize and respect the unique perspectives of those responsible for program development.**

Quality preservice programs are characterized by collaborative efforts involving those concerned with program development, with clear respect for the perspectives and expertise of each person involved.[17] In the context of science teaching, scientists, education and science education faculty members, and experienced teacher practitioners all contribute critical elements to the process of preservice elementary program development.[18] The necessity for clarifying the contributions and particular roles of the participants is of much importance and should include articulation of expectations, commitments, and procedures. Often, these decisions become the critical dilemmas that effective collaborations master.[19]

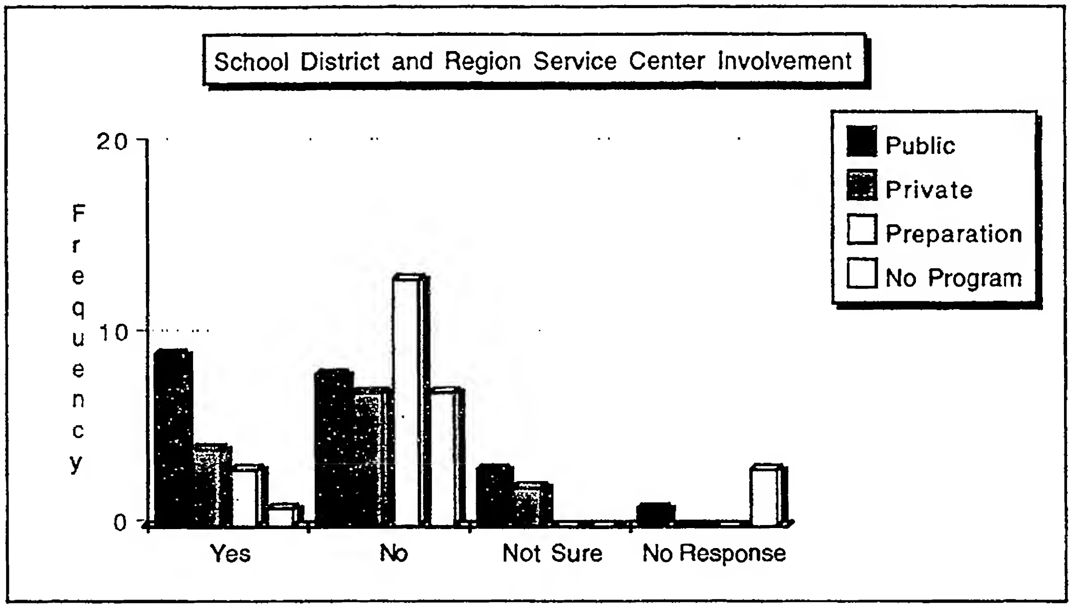


Figure 5. Frequency of Institutional Responses (n=61)
Have school districts and/or region service centers provided input to you concerning what is important to be taught in your science courses for elementary teachers?

The integration of multiple perspectives in the design and execution of elementary preparation programs enhances preservice teacher development. Science department faculty members bring expertise in science content knowledge, while faculties of education contribute expertise in pedagogical knowledge. Schools provide the practical perspective and reinforce the changing needs of students.

Integrating the areas of expertise allows for programs to model diverse pedagogical styles and select content carefully to provide depth and rigor for all students.[20]

> What happened in one school-university partnership when the basic tensions between the theory and practice were discussed in open, honest terms led to the cooperation between the elementary school and the university to successfully integrate the preparation of new teachers and the continuing education of experienced teachers. The result was a collaboratively delivered methods course which serves as a model for future partnerships and became the foundation for a complex relationship between the school and the university. The partnership has changed the elementary school, provided meaningful inservice for practicing teachers, and impacted university teacher preparation. The discovery and understanding emerging from this partnership provides lessons for all school-university collaborations.[21]

Expert teachers can also play a key role in program development. Expert teachers have developed the methods of analysis and action that lead to effective teaching. However, these processes are automatic for them, so it is important for expert teachers and researchers to work together to explain these processes to preservice teachers.[22] In the process of program reform, science faculties, education faculties, preservice teachers, and experienced teachers all have a role to play.[24]

> An outstanding kindergarten teacher illustrates the importance of collaboration.
>
> *I think if you don't get involved with people [scientists and business executives] you don't know that they value your opinion as an educator.* [23]

What do we know about collaborative efforts in teacher training institutions in Texas? Responses to a partially open-ended question on the Texas Survey showed limited evidence that science curriculum was developed collaboratively at educational institutions in Texas. For instance, 50 percent of the respondents said that curriculum guidelines were well established or determined by the department at their institution while 40% of the respondents noted that individual course instructors were responsible for curricular decisions.[25]

- **Collaborative programs are assessed by a variety of stakeholders.**

Ideas of collaboration are both old and new; old in the sense that many people have written about and experienced cooperative working relationships before;[26] and new in the sense that after several decades of reform, there is still a necessity for working together—teachers, students, parents, scientists, educators, administrators, policy makers, and business people in efforts to bring about change and evaluate programs.[27]

Faculties of science and education departments, along with experienced teachers, are essential to reform. However, they do not act alone; they need allies. Therefore, administrators, policy makers, members of professional and scientific communities, parents, and community representatives need to support efforts of elementary program reform and assessment.[28]

> To help ensure that reform does happen, continuing community support for education is essential. Such support is not easy to sustain in the face of changing demographics and changing social priorities. Therefore, informed and determined political leadership at every level and in every sector—government, business, labor, and education—is critical for achieving reform. Without such leadership, community support for educational reform will fade away long before lasting results can be achieved.[29]

Program assessment is a shared responsibility allowing collaboration to capture the perspectives of all those involved in the process. Both formal and informal assessments can provide corrective feedback on the effectiveness of preservice programs, as they are being

implemented. Continuous program assessment uses a variety of strategies, provides focus on the process and effects of the program, and in turn, directly influences program development and evaluation.

Periodic, rigorous assessments that consider satisfaction and performance of all stakeholders can provide policy makers with feedback on how well policy and design are working together. For example, maintaining contact with graduates of an educational program is an important part of evaluating program success.

Feedback from the multiple perspectives of all stakeholders can reveal the range and number of concerns related to the program as it is currently in place. Recommendations for change can then be made on the basis of many perspectives, including preservice teachers, rather than on the perspectives of only one or two powerful groups.

A question on the Texas Survey requested information about how current programs maintain contact with their graduates. How do teacher preparation institutions in Texas currently maintain contact with their graduates? Forty-four percent of the respondents from the Texas Survey indicated that there was not a procedure provided by their institutions to maintain contact with graduates of their program; 31% described a procedure at their institution; and 20% did not respond or did not feel the question was applicable at their institution. Five percent of the respondents were not sure if their institution provided such a procedure. Three categories emerged from the

A university methods instructor describes the relationship she has with the principal at an elementary professional development school. In that school, all grade-level teachers in the building have made a commitment to plan, supervise, and/or co-teach a science lesson every week with their assigned group of preservice teachers.

The principal and I check in informally with each other on a weekly basis to see how things are going. If a problem arises, we put our heads together to decide the best way to solve it. In one instance, a group of preservice teachers in my methods course [was] feeling unappreciated by the classroom teachers. The principal and I discussed the best way to address the preservice teachers' concerns. We decided that the principal was the best one to have an informal discussion with her building teachers and the preservice teachers. The preservice teachers were so surprised to learn that the classroom teachers not only appreciated what they were doing with their students, [but] they [also] wanted copies of the science lessons they had been preparing on their own to teach with their students! I felt that the early intervention improved relationships among both sets of teachers and improved the attitude of my entire class. I know how appreciative my preservice teachers were of the time and consideration given to them by the building principal. Several of the students in that group mentioned in their final portfolios how important a learning experience that one meeting was for them. Informal, continuous "checking in" has become a valuable way for me and the principal to assess how well the program is progressing.[30]

A college instructor describes how local school districts work collaboratively with the university to plan and assess the university program.

We are constantly communicating with at least five school districts in our area. We participate together in planning meetings and have ongoing evaluation of our program.[31]

A college instructor describes how a questionnaire can help institutions maintain contact with graduates to assess the strengths and weaknesses of their program. The procedure is as follows:

Follow-up questionnaires are mailed to each building administrator who hires our certified candidates. This provides our office with knowledge as to the strengths and weaknesses in program delivery.[32]

content analysis of "yes" responses describing the follow-up procedures at their institutions: (1) surveys or questionnaires sent to graduates; (2) informal follow-up procedures for assistance; and (3) regularly occurring procedures like workshops.[33]

All aspects of any system can be analyzed and assessed for growth, progress, and success as an individual entity and as an integrated part of the system. Collaborative partnerships in particular require strict attention to how well the program is matching its goals and objectives and how well the program is matching the expectations of the involved stakeholders. Discussions centering on assessment issues can enhance the communication between and among various stakeholder groups, at the same time reinforcing the goals and expectations of programs to all those within the system who play major roles and have high stakes associated with its continued success.[34]

- **Collaborative programs include professional development as an integral part of improving program design.**

Collaborative efforts that foster integrated professional development must be developed where practitioners and theoreticians are involved in teacher education activities in a collegial relationship.[35] Traditional teacher preparation programs are limited in the opportunities they provide for inservice teachers to be connected to the teacher preparation process that might benefit their own development. These limitations have created a need for teacher preparation programs that involve inservice teachers and faculties of science and education departments in the professional development of preservice teachers, and at the same time create opportunities for their own professional development.[36] Teachers of science involved in the process of professional development can work together with preservice teachers as they integrate their knowledge and experiences. Science centers, industry, and other organizations might also participate in professional development activities.[37]

There are many benefits of collaborative professional development. It creates a program structure that facilitates reflection and action with regard to teaching and learning of science. It

One collaborative formed by a museum, university, and public school system illustrates professional development opportunities as a continuous process for *all* teachers of science. In the design of the collaborative, university faculty, museum staff, elementary teachers, graduate students, preservice teachers, and elementary students worked and learned together. An elementary teacher described her own professional growth experience.

Now when I go to the learning lab, I teach. [The university methods instructor] makes me in charge of teaching in front of undergraduate students. This whole program has really empowered me.

The chief curator at the museum made a similar statement.

For me, it is very exciting and interesting. I am about to retire, and if I wasn't doing this, I would have already retired.

A preservice teacher made these comments about her museum experience.

Before this semester, I was in Language Arts. I hated mathematics, and we had to have science. I hadn't had science or mathematics for fifteen years. I didn't care to take either one. I protested for a year, but now after this semester and working with kids in the museum and the teachers, I had such a positive experience. Now, I am specializing in mathematics and science, whereas before I would not have done it for anything.[38]

has the potential for encouraging greater professional talk and action related to teaching, learning, and school problems.

An outstanding kindergarten teacher in Texas makes the following comment concerning professional development:

[Preservice teachers] have to have science content. They have to have updated content, which means you are going to have your professors keeping up.[39]

School and community leaders working together not only bring more resources to their problem-solving efforts but also develop mutual trust and support that enhance professional development. Collaborative research legitimates teachers' practical understanding and their definition of problems for both research and professional development.[40] Collaborative partnerships are a vehicle for professional development and continual growth, as well as a means to strengthening the science courses offered at the undergraduate level.[41] Some of the most powerful connections between science teaching and learning are made through thoughtful practice in field experiences, team teaching, collaborative research, and peer coaching.[42]

Do Texas institutions encourage professional development? Sixty-one percent of the respondents indicated active encouragement on the part of their institution for new methods of professional development while 28% said their institution did not

encourage such development. There was a "no-response" rate of 8 percent, and 3 % indicated being unsure of the support at their institution (see Figure 6).[43]

Recent national documents identify two-year colleges as needing to become "more significant partners in the system of teacher preparation."[44] With their clear commitment to teaching and with so many prospective teachers as students, instructors in two-year colleges can be powerful role models as effective facilitators of science learning.

One Texas collaborative was recently studied in a doctoral dissertation completed by Dawn Parker that examined several collaboratives in the state that had been formed specifically to strengthen the science preparation of preservice teachers. This particular collaborative involved a two-year college and a four-year comprehensive university, partnered with a local school district. In the collaborative, the science curricular options were offered by the two-year college, and faculty appointments were made jointly between the two-year college and the university. Furthermore, a portion of the faculty member's salary was paid by each institution. A science educator in the collaborative stated, "It has been interesting to have community college personnel on faculty with us. You know, they don't come to our shop often."[45] Parker reported that the Texas Education Agency was not quick to approve the new curricular science specializations

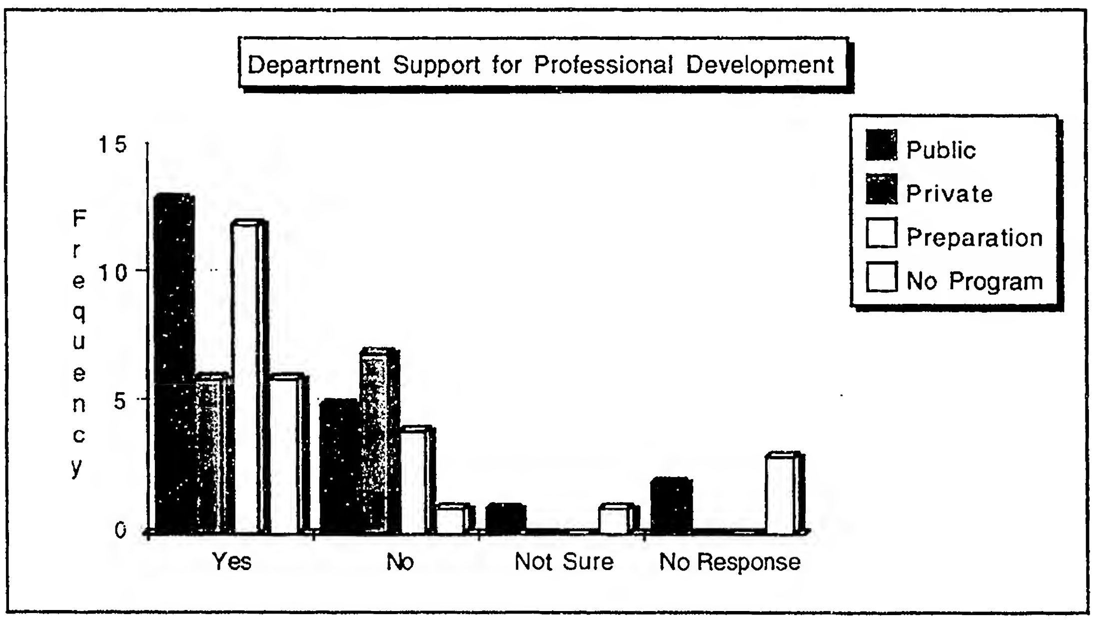


Figure 6. Frequency of Institutional Responses (n=61)
Does your department actively encourage new methods of professional development in teaching science (i.e., involvement in professional educational organizations, collaboratives, and/or presenting at conferences) for faculty?

provided by the community college/university collaborative and explained that many factors contributed to the agency's final decision to approve the science specialization.

> The four science faculty professors involved in teaching the science courses [at the two-year college] all had earned doctoral degrees. This was important in providing credibility to the upper division science courses offered in the specializations. The stability of the two-year college, the commitment of providing faculty, funding, and campus space were vital to program approval. The president of the two-year college addressed this commitment and saw the benefits in joint-appointments of faculty. This voice of commitment helped to win the approval of the curricular science specializations at Educational Institution Two by the Texas Education Agency.[46]

Parker also described the role of students in helping to win the approval for the new joint science program at the university. She said, "Student interest in science was fundamental to the entire collaborative process,"[47] and described a specific incident in which the chemistry professor took a group of students over to the president's office to convince him that the university should provide a science teaching option. She also mentioned that public school teachers wanted the university to provide elementary teaching options in science, quoting a fourth grade teacher who said, "I wish they would have had a science specialization when I was at the university. I wouldn't have a history specialization. I would have a science specialization. All but six of my graduate hours are in science."[48] The collaborative, which is still growing, continues to provide varied science experiences for both preservice and inservice teachers, as well as for children in the community. Two-year and university college faculty continue to explore new ways to infuse science education into the community by involving preservice and inservice teachers in designing and implementing informal science summer programs and school-based mentoring/teaching experiences. These efforts have brought all parties together as members of a learning community who have used the resources of their partners to strengthen the science education programs in each one individually.

Conclusion

In science education reform, there can be no question as to the ultimate recipients of restructured, strengthened educational programs. School children and the schools responsible for a significant portion of their intellectual growth are the recipients. Educators today face public demands for improved school programs that are becoming ever more urgent.[49] "Changes must take root in every community and must reach the great majority of students."[50]

A current issue of the National Science Foundation monograph, *Foundations*, provides an overview of the goal of systemic reform.

> This is the soul of a systemic approach to science education reform; a wide-angle view of school change that sees all aspects of the system as a whole. It recognizes that if changes are to be long lasting, each and every component part of the system must be irreversible and permanently altered.[51]

Integrated, comprehensive approaches to change involve multiple stakeholders committed to common goals. All partners have something to gain that the collaboration can provide. Although needs may vary from partner to partner, all parties can expect to *learn* from the collaboration and to grow in their single and combined efforts to improve the quality of their science programs.

Collaboratives specifically organized to improve the quality of programs that prepare elementary teachers to teach science can have many benefits: they can provide a structure for professional growth and development for all teachers of science involved in the collaborative; they can improve channels of communication with and knowledge about the culture of today's public schools, they can support teachers of science as they learn together how to improve instruction to focus on students' learning in inquiry-based contexts; and they can increase learners' knowledge of science as a unique way of making sense of the natural world, using what they know and can do to solve problems, make decisions, and lead productive lives in our highly advanced technological society. Forming collaborative partnerships can improve preservice education. Effective collaboratives can continually seek new ways to redefine and improve existing partnerships, as well as seek innovative ways to involve new partners who can offer unique perspectives and play significant roles in assuring a quality science education for all students.

Questions to Consider

1. What are effective strategies for bringing stakeholders together to form a collective vision regarding preservice preparation?
2. How can institutions of higher education encourage and support collaborative partnerships across colleges?
3. What incentives for collaboration make sense in the work environments of public schools, colleges and universities, and communities?
4. How can induction-year teachers and postgraduates inform programs that prepare elementary teachers to teach science?

Endnotes

[1]Peter Senge, *The Fifth Discipline* (New York: Doubleday, 1990) 3.

[2]B. A. Intrilligator, "Evaluating Inter-Organizational Relationships," Paper Presented at the Annual Meeting, American Educational Research Association, Montreal, 1983.

[3]Shirley Hord, "A Synthesis of Research of Organizational Collaboration," *Educational Leadership* 43.5 (1986): 22.

[4]K. A. Hoyt, *A Concept of Collaboration in Career Education* (Washington: U.S. Office of Education, 1978).

[5]Shirley Hord, "Distinguishing Between Cooperation and Collaboration: A Case Study Approach to Understanding Their Relative Requirements and Outcomes," Paper Presented at the Annual Meeting, American Educational Research Association, Boston, 1980.

[6]J. Lanier, "Collaboration Session, Discussant Remarks," *Exploring Issues in Teacher Education: Questions for Future Research*, eds. G. E. Hall, S. M. Hord, and G. Brown (Austin: Research and Development Center for Teacher Education, University of Texas, 1979) 408.

[7]A. Hargreaves and M. Fullan, *Understanding Teacher Development* (London: Cassell, 1991) 17.

[8]Hargreaves and Fullan 17.

[9]American Association for the Advancement of Science, *Science for All Americans* (Washington: AAAS, 1989) 224.

[10]Carol Stevens and George Wenner, "Elementary Preservice Teachers' Knowledge and Beliefs Regarding Science and Mathematics," *School Science and Mathematics* 96.1 (1996): 8.

[11]Senta Raizen and Arie Michelsohn, *The Future of Science in Elementary Schools: Educating Prospective Teachers* (San Francisco: Jossey-Bass, 1994).

[12]Dawn Parker, "Collaborative Models for Preservice Elementary Science Preparation at Colleges and Universities in Texas," Ph.D. Dissertation (Texas A&M University, College Station, Aug. 1997) 114.

[13]*Science for All Americans* 224.

[14]Raizen and Michelsohn 120.

[15]Dawn Parker, "Preservice Elementary Science Survey: A Description of Programs at Colleges and Universities in Texas," Report Prepared for the Texas Statewide Systemic Initiative. Charles A. Dana Center (Austin: Sept. 1996) 17.

[16]Parker, "Preservice Survey" 15-16.

[17]National Research Council, *National Science Education Standards* (Washington: National Academy Press, 1996) 70.

[18]Raizen and Michelsohn 119.

[20]National Research Council and National Science Foundation, *Options for Action: Roles of Departments of Science in Teacher Preparation, Proceedings of the NRC/NSF Regional Symposium on Science. Mathematics, Engineering, and Technology Education, Johnson Space Center, Houston* (Washington: National Academy Press, 1996).

[21]Donna Wiseman and Donna Cooner, "Discovering the Power of Collaboration: The Impact of a School-University Partnership in Teaching," *Teacher Education and Practice* 12.1 (1996): 20.

[22]David C. Berliner, "In Pursuit of the Expert Pedagogue," *Educational Researcher* 43.5 (1986): 5-13.

[23]Andrea Foster, "Interviews of Elementary Science Presidential Awardees: Patterns that Portray Excellence in Science Teaching," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996) 16.

[24]*National Science Education Standards* 70.

[25]Parker, "Preservice Survey" 14.

[26]A. Miel, *Cooperative Procedures in Learning* (New York: Teachers College Press, 1952); S. M. Cory, *Action Research to Improve School Practices* (New York: Teachers College Press, 1953).

[27]Ann Lieberman, "Collaborative Work," *Educational Researcher* 43.5 (1986): 5.

[28]*Science for All Americans* 213.

[29]*Science for All Americans* 201.

[30]Carol Stuessy, personal interview, 12 Jan. 1997.

[31]Parker, "Preservice Survey" 16.

[32]Parker, "Preservice Survey" 21.

[33]Parker, "Preservice Survey" 21.

[34]*National Science Education Standards* 76.

[35]*National Science Education Standards* 63.

[36]Sharon Parsons and Karen E. Reynolds, "Establishing an Action Research Agenda for Preservice and Inservice Elementary Teacher Collaboration on Self-Empowerment in Science," Paper Presented at the Annual Meeting, National Association for Research in Science Teaching, San Francisco, 1995.

[37]*National Science Education Standards* 70.

[38]Parker, "Collaborative Models" 140-141.

[39]Foster 18.

[40]Lieberman 31.

[41]Raizen & Michelsohn 134.

[42]*National Science Education Standards* 67.

[43]Parker, "Preservice Survey" 22-23.

[44]National Science Foundation, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Washington: NSF, 1996) 53.

[45]Parker, "Collaborative Models" 92.

[46]Parker, "Collaborative Models" 92-93.

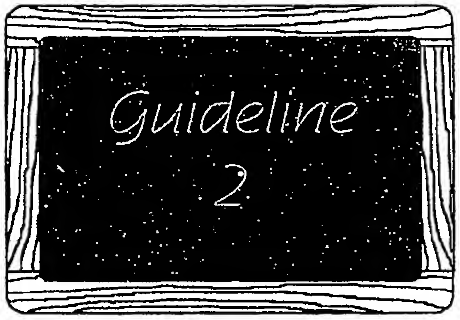
[47]Parker, "Collaborative Models" 94.

[48]Parker, "Collaborative Models" 94-95.

[49]National Science Foundation, *Foundations: The Challenge and Promise of K-8 Science Education Reform* (Washington: NSF, 1997) 4.

[50]*Foundations 4.*

[51]*Foundations* 3.



Science Content and Process

All teachers of science learn the content and process of science through experiences that extend their integrative powers in problem solving and support their active pursuit of answers to questions about the natural and designed world.

This happens when

- Science learning experiences confirm the nature of science as a unique way of knowing about the world.
- Science learning experiences present science as an active process focused on a limited number of unifying concepts that provide powerful understandings about the natural world.
- Science learning experiences present scientific knowledge as a vehicle for explaining how the natural world works and as the predominate force shaping our lives, our communities, and the planet itself.
- Science learning experiences present content in the domains of physical, life, and earth-space science that includes both breadth and depth in fundamental, accurate understanding about the natural world.
- Science learning experiences are designed for learners to integrate their abilities to think quantitatively with or without the use of tools that extend manipulation and observation skills.

On Science Courses for the 21^{st} Century

> To endure the integrity of the curriculum it offers, each science, engineering, and mathematics department needs to engage in a dialogue based on the question: "What should students know and be able to do as a result of the courses they take in our department?" This statement of scholarly mission should include an explicit statement of educational goals. The dialogue should extend to individual courses and to courses of study and should embrace both majors and nonmajors. It should consider issues of content and pedagogy; and it must lead to assessments that can measure whether established goals have been met. . . . Introductory courses for all students should offer a serious encounter with both the processes and essential concepts of mathematics, science, engineering and technology. The courses should be problem-driven, emphasize critical thinking, have hands-on experiences, and be taught in the context of topics that students confront in

> their own lives. Interdisciplinary courses can be particularly valuable in helping students see the links among disciplines and in placing subjects in broader personal, historical, cultural, social, and political contexts.[1]

The thrust of science education reform for the 21st century is towards equal access for all learners, up to and including college undergraduates, to a science education that is useful in the everyday life of learning, living, and working. When the current national reform movement in science education began to take shape in the late 1970s, the predominant theme of "science for all" arrived in the concept of science literacy. *Science for All Americans* brought the concept, as well as a new goal for reform in science education, to center stage.

> Scientific literacy—which encompasses mathematics and technology as well as the natural and social sciences —has many facets. These include being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes.[2]

Key concepts and principles of science are an important focus of this chapter. These comprise that facet of science literacy that entails what preservice elementary teachers should know and be able to do as a result of their undergraduate preparation in science. We know that prospective elementary teachers begin their preservice preparation lacking a strong science background; and that most preservice preparation programs require so much course work other than science that a student may not be able to allocate the time in her program to make up the deficits in her science background. Hawkins and Michelsohn from the National Center for Improving Science Education presented the results of a recent survey of the science content and science pedagogy requirements at 142 teacher education programs.[3] The survey represented a snapshot of the different approaches taken toward educating preservice elementary teachers in the United States. These researchers suggested that the problem of underpreparedness has not been solved in these institutions by increasing the number of science content courses that preservice elementary teachers are required to take for completion of their programs, or even for state teacher certification.

> Unless they are very large, rises in state science requirements may, in fact, have comparatively little effect on the amount of science that preservice teachers take. Most undergraduate programs we surveyed required students to take at least three science courses, and none allowed students to graduate without taking any science courses. While it must be acknowledged that our survey sought out innovative programs, most of the innovations involved the science pedagogy

> part of the program, and did not affect the amount of science taken. Those innovations that were connected with science content generally did not add more content courses, but instead changed their teaching format.[4]

Hawkins and Michelsohn specifically researched questions regarding how much science preservice teachers should take. These authors, as do our *Guidelines*, suggested a solution that is different from increasing the number of science content course requirements. An improvement in the quality of courses, rather than in the quantity, was suggested as being more effective in preparing elementary teachers to teach science that leads to science literacy in their students.[5]

Science literacy remains at the heart of answers to questions regarding what all students should know and be able to do as a result of the courses they take in science. We have excellent resources for identifying relevant science content for K-12 learners. Most visible have been the *Benchmarks for Science Literacy*[6] and the *National Science Education Standards*.[7] At the state level, Texas has just adopted the *Texas Essential Knowledge and Skills in Science*,[8] which will be implemented in every school district as the law mandates by September 1998.

The needs of K-12 science education, as reflected in the new *Texas Essential Knowledge and Skills in Science (TEKS)*, are strongly linked to undergraduate education. These new standards for Texas can also provide framework for the development of undergraduate science curricula that prepare elementary teachers, as well as for the development of science literate public school students. The content described in the *TEKS* is not a science curriculum. The *National Science Education Standards* remind us that "Content is what students should learn. Curriculum is the way content is organized and emphasized; it includes structure, organization, balance, and presentation of the content in the classroom."[9] The implementation of *TEKS*, therefore, does not imply any particular organization for science curricula. Implementation of the *TEKS* does imply, however, careful attention to the goals for which the curriculum was designed and the nature of the learner for which the curriculum was intended.

> Unlike many liberal arts students taking science courses, for prospective elementary school teachers the science they study directly affects their professional lives. Not only must they learn science, they must be able to teach it. To meet these unique needs, program planners at many institutions have developed science content courses for prospective teachers taking into account what school teachers should know, but also what their specific population of prospective teachers needed.[10]

The *Texas Essential Knowledge and Skills in Science (TEKS)* represent the content dimensions of what every public school student should know and be able to do. The *TEKS* also frame the content dimensions of what every public school teacher should be able to know, to do, and to teach. What, then, are the recommendations of the Preservice Elementary Science Action Team regarding the design of curricula for undergraduate preservice elementary teachers?

The second guideline provides a general description of the science experiences recommended for all science learners, including preservice teachers. The action team made five suggestions for the design and choice of science experiences that will support elementary teachers, as well as all other learners of science, in their pursuit of solutions to problems and answers to questions about the natural and designed world.

- **Science learning experiences confirm the nature of science as a unique way of knowing about the world.**

Researchers who have studied the methods of science teaching have found that teachers hold very different conceptions about what science is. Research on science teaching indicates that a teacher's perception of science as a way of knowing reflects the methods that are chosen for teaching science in the classroom, as well as children's conceptions regarding the nature of science.[11] Even though scientists do not spend a lot of time discussing the scientific world view from which they do their work,[12] teachers of science must explicitly represent the world view of science. All science instruction, and particularly that which is aimed at the preparation of teachers of young children, must include clear messages about the nature of science.

Philip H. Phenix in 1964 included science in the category of *Empirics* in his classic book, *Realms of Meaning*. Empirics was characterized by its explanations and theoretical formulations that are "based upon observation and experimentation in the world of matter, life, mind, and society," expressing meanings as "probable empirical truths framed in accordance with certain rules of evidence and verification of making use of specified systems of analytic abstraction."[13] When science is taught as a body of facts to be memorized, the learner has no way to explain the unique way in which science is generated. Even teachers who can state scientific principles correctly sometimes make mistakes when trying to explain certain natural phenomena. Teachers must be confident and fluent enough with the scientific model to lead discussions, provide examples and explanations, and generate problem solving applications.[14]

Just as teachers of science should relay the message of what science *is*, it is also important that they relay what science *is not*. *Science for All Americans* makes that point.

> A kindergarten teacher describes in detail an instructor's use of questioning strategies to get her to think about how oysters who thrive in bay systems got to the Gulf side of the beach. She described his strategy this way:
>
> *It's like being with Socrates because he kept saying, "Think about it." I incorporate his model for teaching into my own classroom pedagogy. I ask similar questions about oysters with my students. Instead of asking students to identify the parts of an oyster, I have them think about how they got where they did and what purpose they might serve.*[15]

> There are many matters that cannot usefully be examined in a scientific way. There are, for instance, beliefs that— by their very nature—cannot be proved or disproved (such as the existence of supernatural powers and beings, or the true purposes of life). In other cases, a scientific approach that may be valid is likely to be rejected as irrelevant by people who hold to certain beliefs (such as in miracles, fortune-telling, astrology, and superstition). Nor do scientists have the means to settle issues concerning good and evil, although they can sometimes contribute to the discussion of such issues by identifying the likely consequences of particular actions, which may be helpful in weighing alternatives.[16]

In learning science, students need to understand that science reflects human history and is an ongoing, changing enterprise. The use of history in school science programs can clarify different aspects of scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures.[17] Students who engage in scientific investigations have a foundation for appreciating the history of science. Historical examples help students to view the scientific enterprise as philosophical, social, and human. To develop understanding of the history and nature of science, the National Research Council recommends the use of actual experiences in student investigations, case studies, and historical vignettes. The National Research Council also warns that the intention is *not* to develop an overview of the complete history of science, but rather as a weaving thread to help students better understand scientific inquiry, the nature of scientific knowledge, and the connections between science and society.[18]

It is within the history *and* the nature of science as a uniquely human endeavor that *Texas Essential Knowledge and Skills in Science (TEKS)* in grades 3 through 8 contain a student expectation that students "connect grade [3] science concepts with the history of science and contributions of scientists."[19] Furthermore, the first principle of science that precedes the *TEKS* in the introduction to each grade level reflects the nature of science as a fundamental concept that comprises all scientific concept areas.

> Science is a way of learning about the world. Students should know how science has built a vast body of changing and increasing knowledge described by physical, mathematical, and conceptual models, and that science may not answer all questions.[20]

What did the Texas Survey reveal regarding how science is taught at the institutions in Texas? Responses to the surveys revealed that 51 percent used lecture as the predominant teaching style. Regarding science laboratory experiences, 67 percent indicated the existence of laboratory experiences; there were no follow-up questions to provide information about the type of laboratory experience. There is no evidence to indicate anything other than verification laboratories, which are the most acceptable and predominant type of laboratory experience

associated with traditional teaching. Carefully constructed laboratory experiences can lead to understandings about science as a way of knowing that uses certain models of inquiry, rules of evidence, and ways of formulating research questions. Traditional laboratories, unfortunately, reinforce the notion that science belongs to the world of "right answers" and inert knowledge.

How can a preservice preparation program provide learning experiences that give undergraduates a feeling for the nature of science? An important trend was noted in the National Science Foundation's recent report on its review of undergraduate education, *Shaping the Future.*

> A valuable way to ground students in the basic processes of SME&T [science, mathematics, engineering, and technology], and perhaps entice them, is to build into introductory courses real or simulated research experiences. The idea is to allow students to experience SME&T as researchers experience it. This design can lead naturally to student discovery of the importance of certain facts.[21]

Innovations designed to improve the quality of all undergraduates' experiences definitely have implications for preservice teachers as well. If elementary teachers are to reflect the nature of science in the design of the learning experiences for their students, they themselves must have a clear concept of science as a way of knowing.

- **Science learning experiences present science as an active process focused on a limited number of unifying concepts that provide powerful understandings about the natural world.**

What is the definition of a *unifying concept* of science, and how does it differ from a scientific fact or theory? Unifying concepts have also been called *basic ideas, big ideas, overarching concepts, unifying constructs,* and *themes.* The notion appears to be the same in all, however. Unifying concepts integrate the concepts of the different science disciplines in ways that are useful to the presentation and teaching of scientific content in order to reinforce the importance of understanding ideas rather than the memorization of seemingly isolated facts. "As opposed to theories, which unify and make sense of facts and hypotheses related to a particular natural phenomenon, themes are pedagogical tools that cut across disciplines."[22] The *Science Framework for the 1996 National Assessment of Education Progress (NAEP)* further describes themes as a "group of inquiry tools that scientists use to better investigate and understand the phenomena with which they deal."[23]

Science literacy not only lies in knowing facts and concepts but also in understanding the connections that make such information manageable and useful. The National Research Council describes their list of broad unifying concepts and processes as "fundamental and comprehensive," as well as understandable and usable by people who will implement science programs. They describe them as complementing the analytic, more discipline-based perspectives presented in their other content standards. The rationale they offer is that the conceptual and

procedural schemes presented in this standard provide students with "productive and insightful ways of thinking about and integrating a range of basic ideas that explain the natural and designed world."[24] An additional rationale, particularly relevant as we think about elementary science preparation, is that many of the unifying concepts and processes can be expressed in learning experiences that are developmentally appropriate for K-12 learners. Each of the concepts and processes has its own "continuum of complexity"[25] that lends itself to the development of vertically articulated curricula and benchmarks at appropriate developmental levels. Such a continuum can be seen in the *Benchmarks for Science Literacy*, which has become an invaluable resource for science educators who have built curricular sequences that span many grade levels. The following sequence on the unifying concept of *model* is an example of how a student might develop a conceptual understanding over the course of her learning experiences in public school science. Sequential learning experiences, carefully planned and implemented, would provide the learners with opportunities to develop a concept of *model* that becomes more abstract and complex over time.

- By the end of the 2nd grade, students should know that

    A model of something is different from the real thing but can be used to learn something about the real thing.

- By the end of the 5th grade, students should know that

    Seeing how a model works after changes are made to it may suggest how the real thing would work if the same were done to it.

- By the end of the 8th grade, students should know that

    Models are often used to think about processes that happen too slowly, too quickly, or on too small a scale to observe directly, or that are too vast to be changed deliberately, or that are potentially dangerous.

- By the end of the 12th grade, students should know that

    The basic idea of mathematical modeling is to find a mathematical relationship that behaves in the same ways as the objects or processes under investigation. A mathematical model may give insight about how something really works or may fit observations very well without any intuitive meaning.[26]

The discussion that precedes the benchmarks on *models* suggests that the term *model* should be used to refer only to physical models in the early grades, and that the notion of *likeness* should be the central issue in using any kind of model. The section further suggests that the curriculum should emphasize a rich variety of experiences, not generalizations about conceptual models. The *Benchmarks* also provide insights into curricular strategies to strengthen students' conceptual understandings of the connection of mathematics to concrete matters and hence, the value of mathematics in modeling. One strategy would be to strengthen students'

understanding of abstract mathematical models by including mathematics in the teaching of science, social studies, technology, health, gym, and music.[27]

One of the basic tenets of science is that the world is understandable through science. Fundamental concepts that cross all disciplines provide "hooks" to new scientific knowledge that continues to explode at ever increasing rates in our fast-paced, technologically driven society. Certain unifying concepts such as *interaction, change, patterns, system,* and *model* hold a consistent place in the acquisition of new knowledge and development of conceptual understanding.

> As students develop and...understand more science concepts and processes, their explanations should become more sophisticated...frequently reflecting a rich scientific knowledge base, evidence of logic, higher levels of analysis, and greater tolerance of criticism and uncertainty.[28]

Scientific knowledge can be organized in many ways. There is no one set way to organize or integrate the overarching concepts of science into a curriculum that spans the science disciplines. The *California Framework* suggests six themes (energy, evolution, patterns of change, scale and structure, stability and systems and interactions). *Science for All Americans* has formulated a similar list (systems, models, constancy, patterns of change, evolution and scale). The *National Science Education Standards* list five groups of "unifying concepts and processes" (Systems, order, and organization; Evidence, models, and explanation; Constancy, change, and measurement; Evolution and equilibrium; and Form and function). *The Science Framework for the 1996 National Assessment of Education Progress* includes three unifying ideas (Systems and their Applications in the Disciplines; and Models and their Functioning in the Development of Scientific Understanding and its Application to Practical Problems; and Patterns of Change, as they are Exemplified in Natural Phenomena).

The Texas Education Agency identified six unifying ideas, or themes, in the design of Coordinated Thematic Science II (structure, energy, systems, changes over time, environmental interactions, and human presence). This curriculum model was developed specifically for interdisciplinary middle school science; the concept of *theme* was defined as an idea that "connects students' discoveries of the natural world to the 'big ideas' of science."[29] That particular curriculum model was unique in that the structure of science disciplinary knowledge was neither subsumed nor "lost" by the thematic focus. An innovative rings-and-spokes design coordinated the thematic emphasis with the more traditional disciplinary focus.[30]

Another Texas example of a curriculum designed with an emphasis on unifying concepts was found in Parker's work on preservice elementary science collaboratives in Texas.[31] The redesign of science content courses offered through the College of Natural Sciences at the university was the primary focus of collaborative efforts. The integrated science courses pre-

sented content in the domains of physical, earth, space, and life science. Content represented both breadth and depth in fundamental, accurate understandings about the natural world. The new integrated science courses were designed to present science as an active process focused on a limited number of unifying concepts that provided understandings about the natural world. The integrated, four-course sequence focused on four themes: (1) systems and structures; (2) energy transformations; (3) change over time; and (4) interactions.

> In the integrated physics course, for example, systems and structures involved particles, their positions, and property classifications. Energy transformations involved both particles and waves. This showed two ways of describing natural phenomena. Changes over time included studies of speed, velocity, and acceleration of particles. Causes and effects of motion and motion changes of projectiles were studied and differentiated. Interactions included forces between particles. Also included was the exchange between systems by demonstrating polluting activities as well as procedures that allowed humans to use the Earth on a sustainable basis.[32]

The new *Texas Essential Knowledge and Skills in Science* also show a thematic emphasis in the three basic scientific principles that introduce the essential knowledge statements and student expectations for each grade level. The scientific principles integrate a number of unifying concepts in these statements.

> Science is a way of learning about the natural world. Students should know how science has built a vast body of changing and increasing knowledge described by physical, mathematical, and conceptual models, and that science may not answer all questions.
>
> A system is a collection of cycles, structures, and processes that interact. Students should understand a whole in terms of its components and how these components relate to each other and to the whole. All systems have basic properties that can be described in terms of space, time, energy, and matter. Change and constancy occur in systems and can be observed and measured as patterns. These patterns help to predict what will happen next and can change over time.
>
> Investigations are used to learn about the natural world through questioning, observing and drawing conclusions. Students should understand that certain types of questions can be answered by investigations, and that conclusions and models built from these investigations change as new observations are made. Models of objects and events are tools for understanding the natural world and can show how systems work. They have limitations and, based on new discoveries, are constantly being changed to more closely reflect the physical world.[33]

The concept of unifying ideas as a way to organize science content is consistent with the National Research Council's notion of curriculum. "Curriculum is the way content is organized

and emphasized, [including] structure, organization, balance, and presentation of the content in the classroom."[34] Incorporation of this approach does not have to mean that scientific disciplinary knowledge is somehow "lost" with the new emphasis; instead, discussions centering on the big ideas of science may assist those of us who come with strong backgrounds in one particular discipline to look at the "big picture" of scientific knowledge. Traditional approaches of thinking about what to teach in science courses center on coverage, depth, and rigor in the presentation of content. Goals of scientific literacy for all students, however, will require new ways of thinking about what to teach in science as well as how to teach it.

- **Science learning experiences present scientific knowledge as a vehicle for explaining the connections between the natural and designed worlds *and* as the predominant force shaping our lives, our communities, and the planet itself.**

An understanding of the connections between the natural and designed world will allow individuals to design problem solutions and make decisions regarding complex issues confronting them in their personal lives, in their lives as wage earners, and in their lives as world citizens in a rapidly changing society driven by technological advancement. William C. Clark makes the case elegantly in the introductory chapter of *Scientific American's* collection of essays titled *Managing Planet Earth.*

> It is as a global species that we are transforming the planet. It is only as a global species — pooling our knowledge, coordinating our actions and sharing what the planet has to offer — that we have any prospect for managing the planet's transformation along pathways of sustainable development. Self conscious, intelligent management of the earth is one of the great challenges facing humanity as it approaches the 21st century.[35]

Clark's statement does not reflect a concern restricted to the 20th century, however, Thomas Henry Huxley in 1880 recognized the significance of the natural sciences.

> The distinctive character of our own time lies in the vast and constantly increasing part which is played by natural knowledge. Not only is our daily life shaped by it, not only does the prosperity of millions . . . depend on it, but our whole theory of life has long been influenced, consciously or unconsciously, by the general conceptions of the universe, which have been forced upon us by physical science.[36]

While *Science for All Americans* speaks "to the intrinsic value of knowing for its own sake," the authors also emphasize the need for education to prepare students to make their way in the real world, a world in which problems abound — in the home, in the workplace, in the community, on the planet.

> Hence, preparing students to become effective problem solvers, alone and in concert with others, is a major purpose for schooling. Science, mathematics, and technology can contribute significantly to that end because in their different

ways they are enterprises in the business of searching for solutions to problems ranging from the highly theoretical to the entirely concrete. Moreover, in their interactions with society, science and technology create the context for many personal and community issues.[37]

What does an elementary teacher do to show the connections between science, society, and technology? This exemplary intermediate elementary science teacher explains the ways that she made natural connections with the children that she taught.

I'd have sky watch parties out on the parking lot and then the administrators allowed me to take students on field trips on Saturdays and Sundays to all the different exhibits that came into the Houston area and to focus on societal issues like cleaning up the beach and those kinds of things.[38]

The format of the *Texas Essential Knowledge and Skills Science (TEKS)* indicates the role of science in today's society by providing an initial statement and suggestions [numbered as (1) in the introduction to each grade level] about teaching science. Three examples follow.

- In kindergarten, science introduces the use of simple classroom and field investigations to help students develop the skills of asking questions, gathering information, communicating findings, and making informed decisions. Using their own senses and common tools such as a hand lens, students make observations and collect information. Students also use computers and information technology tools to support their investigations.[39]

- In grade 1, the study of science includes simple classroom and field investigations to help students develop the skills of asking questions, gathering information, making measurements using non-standard units, with tools such as a thermometer to extend their senses, constructing explanations, and drawing conclusions. Students also use computers and information technology tools to support their investigations.[40]

- In grade 2, the study of science includes planning and conducting simple classroom and field investigations to help students develop the skills of making measurements using standard and non-standard units, using common tools such as rulers and clocks to collect information, classifying and sequencing objects and events, and identifying patterns. Students also use computers and information technology tools to support their investigations.[41]

A progression of skills is suggested so that in later grades, students begin to plan and implement field and laboratory investigations using scientific methods (beginning in grade 4). The use of tools also increases in complexity, with the addition of compasses, microscopes, cameras, spring scales, calculators, and telescopes in later grade levels.

A similar progression can be seen in the second introductory statement that explains what students will learn at each grade level. For instance, the introductory statement about kindergarten science provides teachers with information about what they will be teaching in regard to science content within the context of what the students will be doing.

> As students learn science skills, they identify components of the natural world including rocks, soil, and water. Students observe the seasons and growth as examples of change. In addition, kindergarten science includes the identification of organisms and objects and their parts. Students learn how to group living organisms and nonliving objects and explore the basic needs of living organisms.[42]

The format of the actual statements mandating knowledge and corresponding student expectations elucidates the science standard in specific terms regarding what the student should know and be able to do. As an example, a knowledge statement and its two related student expectations appear below.

(K.10) Science concepts.

The student knows that the natural world includes rocks, soil, and water.

The student is expected to:

(a) observe and describe properties of rocks, soil, and Water; and

(b) give examples of ways that rocks, soil, and water are useful. [43]

Other *Texas Essential Knowledge and Skills in Science (TEKS)* statements stress the integration of science and technology through scientific process knowledge statements. Such a strand of *TEKS* statements begins in grade 3 and continues to grade 12. This strand stresses the importance of the student being able to draw inferences based on information related to promotional materials for products and services; evaluate the impact of research on scientific thought, society, and the environment; and connect the science concepts at that grade level with the history of science and contributions of scientists. The implication for preservice education is that preservice students need not only understand and be able to perform each of the *TEKS*; they must also understand how the *TEKS* at each grade level articulate with those coming before and after them. These individual knowledge statements and their associated statements of student expectations were developed with careful consideration of developmental appropriateness and a hierarchical understanding of how concepts and skills build on one another.

- **Science learning experiences present content in the domains of physical, life, and earth and space science that includes both breadth and depth in fundamental, accurate understandings about the natural and designed world.**

This indicator speaks to the concept of "less is more," as rationalized in the *Benchmarks for Science Literacy*.

> *Benchmarks* demands more of students than is now customary — more depth, more connectedness, more relevance. But it demands of them far less memorization of isolated facts and concepts than the great compendium of miscellaneous topics confronting them today in the required science and mathematics curriculum. Learning important ideas in any useful way simply takes more time than has usually been assumed, at least in part because many ideas in science and mathematics are abstract and not in accord with everyday experience.[44]

"Covering the book" is no longer an appropriate strategy for defining science curriculum. Remembering the *Standards'* definition of curriculum as the way content is organized and emphasized, including structure, organization, balance, and presentation of the content,[45] the curriculum designer/instructor is faced with a new challenge: how to choose the most appropriate content for the goals of instruction and the developmental level of the learner. Standards-based curricula use documents such as the *Benchmarks for Science Literacy, National Science Education Standards,* and the *Texas Essential Knowledge and Skills in Science* as a foundation for their choice of content that represents breadth, depth, and fundamental, accurate understandings about the natural world. These documents mirror the principles of Philip Phenix regarding the selection of content: "From the large resources of material in any given discipline, those items should be chosen that are particularly *representative* of the field as a whole;"[46] and "content should be chosen so as to exemplify the *methods of inquiry* and the modes of understanding in the discipline studied."[47]

The *Texas Essential Knowledge and Skills in Science (TEKS)* form the framework for Texas schools that identifies what every public school student should know and be able to do in science. By design, the *TEKS* were developed to represent categories of understanding. The categories in grades K-8 were not restricted to labels representing the traditional disciplines of science, although some concepts may appear to "belong" to one discipline more than to another. Instead, the overall intent was to choose content that would represent the essential knowledge and skills that would lead to science literacy in the public school children of Texas.[48]

The *Texas Essential Knowledge and Skills in Science (TEKS)* provide flexibility at the local level by allowing both vertical and horizontal articulation of content. The *TEKS* do not present content in grades K-8 contained as packets of information within larger envelopes of content labeled with the familiar disciplines of science. Without rigidly bounded content area divisions, concept strands can easily be constructed from grade level to grade level (or in undergraduate courses, from course to course), with a seamless integration from one level to the next. For instance, the sequence of *TEKS* associated with the concept of "system" would begin with developmentally appropriate science experiences in kindergarten that would later connect with "system-related" science experiences at later grade levels. Development of the

"big idea" of "system" would therefore occur over time, with concepts experienced at earlier grades providing the foundation for later learning.

The *Texas Essential Knowledge and Skills in Science (TEKS)* would provide the same flexibility in preservice elementary preparation programs designed to strengthen the science preparation of undergraduate preservice students. For whatever group of students, however, it is important to remember that the *TEKS* were not designed to limit the science experiences of learners to those *TEKS* prescribed by the law. Instead, they were chosen to be representative of scientific knowledge that is *fundamental* to understanding the natural and designed world: knowledge that follows guidelines such as those established by the National Science Education Standards in that the content

- Represents a central event or phenomenon in the natural world;
- Represents a central scientific idea and organizing principle;
- Has rich explanatory power;
- Guides fruitful investigations;
- Applies to situations and contexts common to everyday experiences;
- Can be linked to meaningful learning experiences; and
- Is developmentally appropriate for students at the grade level specified.[49]

Well prepared preservice teachers will possess the essential knowledge and skills represented in the *Texas Essential Knowledge and Skills in Science (TEKS).* They will be able to apply and extend their knowledge and skills in their pursuit of questions as learners of science, as well as model the pursuit of scientific questions to their students in the classroom. Science teacher educators can help teachers recognize the flexibility, breadth, depth, and connectedness of the science content in the *TEKS* framework. Well prepared teachers will understand that the *TEKS* framework provides for both vertical and horizontal articulation in the curriculum. Finally, the well prepared preservice teacher will understand the philosophies underlying standards-based teaching and learning. The *TEKS, Benchmarks,* and *Standards* provide a conceptual organization for science knowledge. *Standards* documents exemplify the concepts of "less is more" and "science for all students," reflecting the goal of the national science education community to strengthen the science literacy of all students.

- **Science learning experiences are designed for learners to integrate the abilities to think quantitatively with or without the use of tools to extend manipulation and observation skills.**

The scientific way of thinking is neither mysterious nor exclusive. The skills involved can be learned by everyone, and once acquired they can serve for a lifetime regardless of one's

occupation and personal circumstances. "That is certainly true of the ability to think quantitatively, simply because so many matters in everyday life, as in science and many other fields, involve quantities and numerical relationships."[50] Computation, estimation, and use of calculators and computers are perceived as skills that are integral to understanding how the world works.

The development of good quantitative thinking skills and learning about the world go together.[51] "It is not sufficient for students to learn how to perform mathematical operations in the abstract if they are to become effective problem solvers and to be able to express their arguments quantitatively whenever appropriate."[52] The *Benchmarks* recommend that teaching at all levels in all subjects should include problem solving that requires students to make calculations and check their answers against their estimates and their knowledge.[53] Use of calculators and computers requires students to be able to select appropriate algorithms, carry out basic mathematical operations on paper, judge the reasonableness of the results of a calculation, and round off insignificant numbers, thus increasing the likelihood that students will learn to use the technology effectively.[54] Early, continuing, and broadly based experiences with calculators and computers have the additional advantage of actually helping students learn mathematics and acquire quantitative thinking skills.[55] Science learning provides an opportunity for students to value mathematical thinking, computation,

An exemplary first grade science teacher explains her first graders' use of mathematics in estimating how much sand a hermit crab would need to cover itself.

I have four hermit crabs that are a pretty good size and one of those came out of his shell and would not go back in. We did not have another shell that was big enough for the crab to switch it. So finally we got sand and [the students] built it up. We looked in a book and it said that they like to bury themselves in sand. So the children were over there measuring the height of that shell to see that the crab had four inches of wet sand.

[The conversation she had with her students, as she told it, follows.]

Teacher: *What are you guys doing with a marker on the side of that cage?*
Student: *Well, we are marking it because we need four inches of wet sand.*
Teacher: *Where did you get that information?*
Student: *It says that they need enough wet sand to cover up. And he's four inches tall.*
Teacher: *That crab is not any four inches.*
Student: *Well, the whole top of the shell is.*
Teacher: *Well, he's not in the shell now. He is out of it.*
Student: *I know, but [more sand] will [help] him be able to cover up.*
Teacher: *Ok, that's fine. Go for it. We'll see if he likes it.* (Noticing the crab had in fact gone all the way to the bottom of the cage . . .) *Did you find something out in your observation?*
Student: *Yes, we were right.*[56]

and estimation. Less concentration on computation in mathematics classes is supported by reforms in mathematics, and more concentration on estimation leads to confidence and sensibility in approximating solutions to problems.

Just as science-literate individuals use calculators and computers to extend and enhance their mathematical thinking, they also use an array of mechanical, electrical, electronic, and optical tools to extend their manipulation and observation abilities.

> Tools, from hammers and drawing boards to cameras and computers, extend human capabilities. . . In daily living, people have little need to use telescopes, microscopes, and the sophisticated instruments used by scientists and engineers in their work. But the array of mechanical, electric, electronic, and optical tools that people can use is no less than awesome.[57]

Benchmarks suggest that K-12 students use a wide array of tools to build, measure, mix dry and liquid materials, make observations, make safe electrical connections, read analog and digital meters, use cameras and tape recorders for capturing information, follow instructions in manuals, and troubleshoot common mechanical and electrical systems. Science literacy includes not only the use but the ability to thoughtfully choose the appropriate tool.

Texas is no exception to national recommendations regarding quantitative skills. The *Texas Essential Knowledge and Skills in Science (TEKS)* require learners to think quantitatively with and without the use of all kinds of tools to extend manipulation and observation skills. The statements from the *TEKS* do not provide an isolated list of tools that children should be able to use. Rather, the use of the tools appears in integrated statements at each grade level distinction. *TEKS* at all grade levels demonstrate a depth and breadth in the expectations of students' abilities to think quantitatively with and without the use of all kinds of tools to extend their manipulation and observation skills.

Effective elementary teachers must not only possess these skills; they must also be able to teach them to children who are just beginning to experience the world with their emerging skills in quantitative thinking.

Effective elementary teachers display positive attitudes towards science and mathematics and are self-confident in their abilities to teach mathematics-related skills.[58] Confident teachers have high yet appropriate expectations for their mathematics and science students. How a teacher motivates her students to learn mathematics and science is a critical factor in students' later science and mathematics performance. Researchers have explored the motivational mechanisms and processes that affect students' success on cognitive tasks, making strong statements about the role of teachers in establishing maladaptive and adaptive motivational patterns in chidren .[59] Gender differences in boys and girls in mathematical and verbal abilities have been explained in terms of different motivational patterns for the two sexes. The role of

the teacher in providing appropriately challenging tasks for children is critical in establishing adaptive motivational patterns that lead children to explore, initiate, and pursue learning tasks that promote their intellectual growth. Preservice teachers, who themselves feel inadequately prepared in mathematics and science, often have lower expectations for children than those who are confident of their own abilities to provide challenging learning experiences in mathematics and science.

> The motivational research is clear in indicating that continued success on personally easy tasks is ineffective in producing stable confidence, challenge seeking, and persistence. Indeed, such procedures have sometimes been found to backfire by producing lower confidence in ability. Rather, the procedures that bring about more adaptive motivational patterns are the ones that incorporate challenge, and even failure, within a learning-oriented context and that explicitly address underlying motivational mediators. For example, retaining children's attributions for failure (teaching to attribute their failure to effort or strategy instead of ability) has been shown to produce sizeable changes in persistence in the face of failure, changes that persist over time and generalize across tasks.[60]

Conclusion

Many undergraduates who choose elementary teaching as a career have themselves been the products of elementary teachers who were not well prepared in mathematics or science. The problems associated with remolding undergraduates' perceptions of themselves as successful in mathematics and science, as well as enhancing their knowledge and skills in these two domains, are complex, ill-defined, and pervasive. Only now are educators beginning to understand the complexity of the problem. Those who prepare elementary teachers in mathematics and science are seeking new solutions that can be effortfully applied during the short period of undergraduate preparation. Adoption of standards for developing science curricula used to prepare preservice teachers may settle many of the difficult questions about what to teach. Awareness of research findings[61] regarding motivational patterns and beliefs about self-efficacy will heighten the awareness of the complexity of the problems facing teachers of preservice teachers and provide insights into the design of solutions at the local level. Preservice teachers who become successful mathematics and science teachers will have been prepared by educators who themselves have the knowledge, skills, and insights to implement effective strategies.

Questions to Consider

1. What is science literacy? How is it best achieved?
2. What is the relationship between scientific literacy and technological literacy?
3. What are the similarities and differences regarding the needs of future majors in science, mathematics, and engineering versus future majors in elementary education? What are the political and economic realities involved in defining courses specific to students' needs?
4. How best can preservice teachers be exposed to the methods and processes of scientific research?
5. How can faculty be encouraged to work together to enable students to recognize connections across disciplines?
6. Given the limitations of available time in preservice teachers' undergraduate preparation program, how can students best acquire the prerequisite knowledge and skills to become successful elementary teachers of science?

Endnotes

[1]National Research Council, *National Science Education Standards* (Washington: National Academy Press, 1996) 21.

[2]American Association for the Advancement of Science, *Science For All Americans* (Washington: AAAS, 1989) 20.

[3]Simon Hawkins and Arie M. Michelsohn, *The Preparation of Elementary School Teachers in Science: Reporting on 142 Preservice Programs* (Washington: The National Center for Improving Science Education, 1995).

[4]Hawkins and Michelsohn 27.

[5]Hawkins and Michelsohn.

[6]American Association of the Advancement of Science, *Benchmarks for Science Literacy* (New York: Oxford UP, 1993).

[7]*National Science Education Standards.*

[8]Texas Education Agency, *Texas Essential Knowledge and Skills in Science* (Austin: TEA, Sept. 1997).

[9]*National Science Education Standards* 111.

[10]Hawkins and Michelsohn 27.

[11]Norman Lederman and M. Druger, "Classroom Factors Related to Changes in Students' Conceptions of the Nature of Science," *Journal of Research in Science Teaching* 22 (1985): 649-662; Norman Lederman and D. L. Zeidler, "Science Teachers' Conceptions of Science: Do they Really Influence Teaching Behavior?" *Science Education* 71 (1987): 721-734.

[12]*Benchmarks* 5.

[13]Philip H. Phenix, *Realms of Meaning: A Philosophy of the Curriculum for General Education* (New York: McGraw-Hill, 1964) 6.

[14]Deborah C. Smith and Daniel C. Neale, "The Construction of Subject-Matter Knowledge in Primary Science Teaching," *Advances in Research on Teaching* 2 (1991): 187-243.

[15]Andrea Foster, "Interviews of Elementary Science Presidential Awardees: Patterns that Portray Excellence in Science Teaching," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996) 8.

[16]*Science For All Americans* 3.

[17]*National Science Education Standards* 107.

[18]*National Science Education Standards* 170.

[19]*Texas Essential Knowledge Skills in Science* A-12.

[20]*Texas Essential Knowledge Skills in Science* A-12.

[21]National Science Foundation, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Washington: NSF, 1996) 44.

[22]California State Board of Education, *Science Framework for California Public Schools Kindergarten through Grade Twelve* (Sacramento: CSBE, 1990) 26.

[23]National Assessment Governing Board, *Science Framework for the 1996 National Assessment of Education Progress: NAEP Science Consensus Report* (Washington: NAGB, 1996) 16.

[24]*National Science Education Standards* 115.

[25]*National Science Education Standards* 115.

[26]*Benchmarks* 268-270.

[27]*Benchmarks* 267.

[28]*National Science Education Standards* 117.

[29]Carol L. Stuessy and Bruce M. Payne, *Coordinated Thematic Science II* (Austin: Texas Education Agency, 1994) 36.

[30]Stuessy and Payne 43.

[31]Dawn Parker, "Collaborative Models for Preservice Elementary Science Preparation at Colleges and Universities in Texas," Ph.D. Dissertation (Texas A&M University, College Station, Aug. 1997).

[32]*Collaborative Models* 70-71.

[33]*Texas Essential Knowledge and Skills in Science* A-1.

[34]*National Science Education Standards* 111.

[35]William C. Clark, "Managing Planet Earth," *Readings from Scientific American: Managing Planet Earth* (New York: Freeman, 1990) 1-2.

[36]*Scientific American*, special edition, March 1996.

[37]*Benchmarks* 282.

[38]Foster 6.

[39]*Texas Essential Knowledge and Skills in Science* A-1.

[40]*Texas Essential Knowledge and Skills in Science* A-5.

[41]*Texas Essential Knowledge and Skills in Science* A-8.

[42]*Texas Essential Knowledge and Skills in Science* A-1.

[43]*Texas Essential Knowledge and Skills in Science* A-4.

[44]*Benchmarks* 320-321.

[45]*National Science Education Standards* 111.

[46]Phenix 11.

[47]Phenix 11.

[48]Jim Collins, *Texas Essential Knowledge and Skills in Science*, Paper Presented at the Annual Meeting, Conference for the Advancement of Science Teaching (Fort Worth, TX: Oct. 1997).

[49]*National Science Education Standards* 109.

[50]*Benchmarks* 288.

[51]American Association for the Advancement of Science, *The Liberal Art of Science: Agenda for Action* (Washington: AAAS, 1990); *Benchmarks* 288-289.

[52]*Benchmarks* 289.

[53]*Benchmarks* 289.

[54]*Benchmarks* 289.

[55]*Benchmarks* 292.

[56]Foster 12.

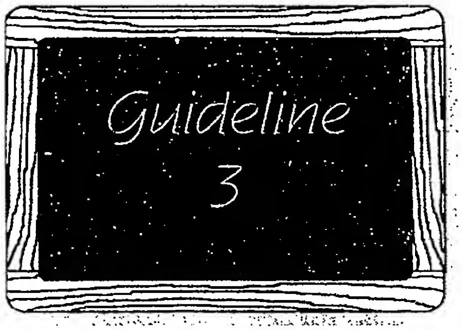
[57]*Benchmarks* 292.

[58]Iris M. Riggs and Larry G. Enochs, "Toward the Develoment of an Elementary Teacher's Science Teaching Efficacy Belief Instrument," *Science Education* 74.6 (1990): 625-37.

[59]Carol S. Dweck, "Motivational Processes Affecting Learning," *American Psychologist* 41.10 (1986): 1040-1048.

[60]Dweck 1046.

[61]Dweck; Sheila Tobias, *They're Not Dumb, They're Different: Stalking the Second Tier* (Tucson: Research Corporation, 1990); Sheila Tobias, *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't* (Tucson: Research Corporation, 1992); Elaine Seymour and Nancy M. Hewitt, *Talking About Leaving: Why Undergraduates Leave the Sciences* (Boulder: Westview Press, 1997); Senta A. Raizen and Edward D. Britton, *Bold Ventures: Patterns Among Innovations in Science and Mathematics Education*, Vol. 1 (Boston: Kluwer Academic, 1997).



Student-Centered Teaching

All teachers of science deliver science content knowledge in a way that positions the student at the center of the teaching and learning process.

This happens when

- Current theories of teaching and learning guide a student-centered approach to the teaching of science.
- Instructional strategies are tailored to enable learning for all students.
- Appropriate assessments are designed to provide analytical, helpful, and informative feedback to all students.
- Stimulating learning environments are structured to enhance learning for all students.

On Student-Centered Teaching

> The personal activity of the student must be placed at the base of the educative process; all the teacher's art must come down to directing and regulating this activity.[1]

According to Vygotsky, a teacher can teach students only through continual collaboration with them and with their social milieu, with their desires and readiness to act together with their teachers.[2] The essence of Vygotsky's ideas are captured in this guideline for strengthening the science preparation of elementary teachers in Texas. Student-centered teaching positions the student at the core of the learning process. Emphasis on students' thought processes and understanding of science is critical for effective instruction and optimal student achievement. This means instructional strategies, assessment procedures, and learning environments for science are designed with students' diverse understandings, needs, and interests in mind. Theoretically, the teacher's role in the teaching and learning of science becomes that of a learning facilitator where students are provided with rich and exciting opportunities for thinking about what they do in science and describing what they understand.

According to the *National Science Education Standards*, "skilled teachers of science have special understandings and abilities that integrate their knowledge of science, curriculum, learning, teaching, and students."[3] Such knowledge allows teachers to tailor learning

environments to the needs of individuals and groups. This unique knowledge, known as *pedagogical content knowledge*, distinguishes the science knowledge of teachers from that of scientists.[4] A science teacher's pedagogical content knowledge weaves together knowledge of science content and pedagogy to efficiently and optimally deliver those particular science concepts to a group of learners.

Much of student-centered science teaching involves predicting which concepts students will find difficult, assessing the misconceptions students may have about particular concepts to be taught, knowing particular sets of science activities that might help students learn certain concepts, and anticipating which concepts might require multiple experiences of understanding. This pedagogical content knowledge requires an understanding of content, pedagogy and much more.[5] Knowledge of learning theory, an understanding of how learning occurs and is facilitated, is an important component of student-centered teaching. To illustrate, teachers of science who know that learning is an active process by which students individually and collectively achieve understanding use their pedagogical content knowledge to make effective decisions about learning, teaching strategies, and assessment.[6] These decisions are impacted directly by the needs, interests, and abilities of their students.

Effective teachers of science continuously develop a broad repertoire of instructional strategies to engage all students in a variety of ways. In addition, effective student learning requires feedback. The mere repetition of tasks by students—whether manual or intellectual—is likely to lead to improved skills or keener insights.[7] Feedback on students' learning that is instructive to both teacher and learner leads to deeper scientific understanding. Feedback that is most helpful to learners consists of more than the provision of correct answers. Worthwhile assessment involves feedback that is analytical, suggestive, informative and communicates the expectations of the science education system to all concerned with science education.

Skilled teachers of science know how to create and manage the physical, social, and intellectual environments in a classroom community of diverse learners.[8] As facilitators of learning, teachers model and encourage appreciation for students' cultural heritages, unique endowments, learning styles, interests, and needs.[9] Student-centered teaching is reinforced by contemporary theories of teaching and learning, the design of appropriate instructional strategies, assessments, and learning environments that have the students' abilities and interests in mind.

- **Current theories of teaching and learning guide a student-centered approach to the teaching of science.**

Student-centered instruction is an approach to teaching science in which students are positioned at the heart of the instructional process. Student-centered instruction in science must reflect the best of what we know about how learning occurs. Science educators need

information regarding the developmental principles and strategies for enabling students to construct their own understanding of important science concepts. While contemporary theories of learning support student-centered instruction, much of what prospective teachers are taught is rooted in the behavioral soil of the nutrient deficient stimulus-response theory.[10] Today's scholars suggest that it is time to replant our ideas about teaching and learning in the rich fields of this new conception of science learning commonly referred to as the *constructivist view* of learning.[11] Constructivism can be defined as a dynamic and interactive model of how humans learn. According to this theory, students "redefine, reorganize, and elaborate their current concepts through interactions with objects, peers, and events in the environment."[12] The constructivist-based approach proposes a deeper understanding of how students learn science. Science teachers who acknowledge this relevant theory of teaching and learning promote student-centered instruction. From Vygotsky's point of view, the main figure in the collective activity of teaching and learning is learning as the *authentic subject*. The teacher can only direct and guide the learner's personal activity with the intent of encouraging further development.[13]

Science For All Americans highlights five student-centered principles of learning that are recognized by those designing beneficial instructional experiences. Each principle emphasizes student learning.

- Learning is not necessarily an outcome of teaching.
- What students learn is influenced by their existing ideas.
- Progression of learning is usually from the concrete to the abstract.
- People learn to do well only when they practice doing.
- Expectations affect performance.

With these principles in mind, teachers of science are more likely to craft teaching and learning experiences that attend to students' attention, learning and memory, comprehension, and motivation. Students' perceptions and expectations regarding their self-concepts, school, teacher beliefs and behaviors, classroom instructional practices, and cognitive processes mediate learning and achievement in science.

An elementary science presidential awardee describes how she transformed a negative college science experience into a positive learning experience regarding pedagogical science content knowledge.
I actually learned to appreciate how to teach science when I [took] a college physics class. There were 350 in the lecture. I had a 42 average and wanted to drop the course. But the professor told me that my grade would be a B. I said that my 42 meant that I didn't understand 58% of the content in the course. He told me to just memorize the formulas for the tests and I would do fine. I knew at that point that was not the way to teach science.[14]

Current theories and philosophies of teaching and learning are important background knowledge for all who teach science. This knowledge provides the necessary foundation for the development of meaningful methodological and instructional practices that direct classroom focus on the student. Paradoxically, education courses in philosophy and pedagogy are viewed as irrelevant and insignificant by many students. Perhaps this is because they are unable to make the necessary connections to their own science teaching experiences.

College instructors can recognize that prospective elementary science teachers, as do all learners, have some fallacious existing prior knowledge and beliefs about science and science teaching that may interfere with their learning of science. These beliefs may be firmly embedded and will require thoughtful and creative teaching methodologies to help students achieve better, more accurate understandings of science. One way instructors can recognize and interpret prior knowledge is by inquiring about students' understanding of concepts. Knowledge of these preconceptions can influence what is taught and how it is taught. It is important to recognize that teachers construct knowledge about teaching in much the same way that children make sense of their surroundings. In fact, some science teachers hold beliefs about teaching and learning that arise from common sense knowledge, not from what they learn in science methods courses. These beliefs appear to be based on well established, idiosyncratic memories of previous teachers, from prior teaching and learning experiences, and childhood events.[15]

Teachers of science reflect on their college philosophy and theory courses and realize through some conceptual change process that what they have been doing in their classrooms is similar to how they were taught. Paradigm shifts occur and adjustments are made to accommodate the student in the learning process.

> A nationally recognized elementary science teacher describes how her preservice science pedagogical content knowledge preparation was quite different from what she encountered in her first grade classroom. She explains how she reorganizes her instruction to improve science learning.
>
> *I think what I was taught is totally different from what I do in the classroom. I took chemistry and biology courses. After a while you realize that you were using some of the knowledge and skills to impart information to your students. I could have used the information to give them questions and let them discover things for themselves instead of spoon feeding them. But I wasn't taught that way. I have revamped my instruction and now I give out less information and do more discovery lessons. I don't know that information was presented to me that way in college.*[16]

- **Instructional strategies are tailored to enable learning for all students.**

The use of a variety of instructional strategies is the key to promoting learning.[17]

Teachers of science select teaching strategies that support the development of student understanding and nurture a community of learners. Over the years, educators have developed many teaching and learning models relevant to the enhancement of science teaching.[18] Effective teachers of science combine these models with a practical structure for the sequence of activities, general strategies, and science content to be learned. In addition, the needs and interests of diverse groups of learners are addressed through the selection of appropriate instructional strategies. The teacher not only respects and is sensitive to all learners but also encourages the use of their skills and talents. As the facilitator of learning, the teacher models and encourages appreciation for students' cultural heritage, unique endowments, learning styles, interests, and needs. The teacher designs learning experiences that show consideration for these student characteristics.[19]

Planning is essential to provide opportunities for all students to learn science. Therefore, planning is heavily dependent on the teacher's awareness and understanding of diverse abilities, interests, and cultural backgrounds of students in the classroom. A wise balance of content and learning and instructional strategies provides a foundation for effective science instruction. An effective teacher of science carefully crafts lessons that are appropriate for the ability level of her students. She pays attention to the features of the content and strategies to be learned in a lesson, particularly as they relate to what the student already knows and is able to do. She plans her lessons also with a sensitivity to student views that might conflict with current scientific knowledge and employs teaching strategies that help to support alternative ways of making sense of the world while developing scientific explanations.[20]

Effective science teachers are mindful of strategies that allow for full participation of all students. Encouraging academic discourse and interaction among individuals and groups in the classroom is vital to deepening the understanding of scientific concepts and the nature of scientific ventures.[21] The decision regarding whether to use whole-group instruction, small-group collaboration, or individual work depends on the teacher's knowledge of the students, science content, and inquiry procedure to be emphasized.

Scientific concepts are best taught by having students reason from the concrete to the abstract. Instructional strategies, which should be anchored to the teaching of science content, can assist in delivering scientific concepts at an appropriate level of abstraction. Effective teachers find ways to develop judgment regarding which strategies are likely to be appropriate for teaching science in particular contexts.[22] Instructors who focus on real phenomena in the classrooms, outdoors, or in laboratory settings, where students design worthwhile investigations

The following two comments are representative of outstanding elementary science teachers' reflections regarding their teaching of science. They demonstrate how exemplary science teachers tailor instructional strategies to meet the needs of their learners, how they know that teaching must be natural and come from the heart.

I don't think there is anything that I can't teach kindergarteners if I can show it to them. I think if you just verbalize, a lot of them are not language developed, but, I think if they can do it and look at it and dance it and eat it and sing it . . . then they learn.[23]

I have never been somebody in which you can hand me a guide and say, "Just teach this." I'll go through the guide and look at the activities I like and copy them and put them in a file . . . the guide usually goes on a shelf somewhere; because I have got to be able to teach from the heart and not from sitting with a book and have the questions in front of me. It has to be natural.[24]

and acquire and interpret information, model useful and effective science teaching methodologies.

According to the Texas Survey, Texas educational institutions are generally traditional in their approach to teaching science and science pedagogy.[25] Lecture is the predominant teaching strategy used by instructors throughout the state even though the professional development standards emphasize learning science through investigation and inquiry rather than by lecture and reading.

Technology can enhance the delivery, interaction, and translation of science content knowledge.[26] The integration of technology into science education and general science courses is also desirable. Technological products provide tools that promote understanding of natural phenomena; and technology provides students and instructors with exciting tools to conduct inquiry and to understand science. Students who are provided with opportunities to observe the use of technology also have opportunities to be active and to participate in its use.[27] Computer-based learning tools, called *mindtools*,[28] can extend cognitive functioning during learning, engaging learners in cognitive operations while constructing knowledge that they would not otherwise have been capable. David Jonassen argues that mindtools enhance conceptual understanding.

> Students cannot use these tools without thinking deeply about the content they are learning, and . . . that, if they choose to use these tools to help them learn, the tools will facilitate the learning and meaning-making process.[29]

With the use of mindtools, which include databases, spreadsheets, semantic networks, animation, and hypermedia, student learning is active and constructive and leads to each individual's organization of experience into knowledge structures; and teaching focuses away from the more teacher-directed instructional strategies and towards instructional strategies that encourage shared decision making and ownership in the teaching/learning process.

Effective science instructors employ a multitude of carefully conceived science teaching strategies that make use of technology and contemporary models of teaching and learning that emphasize the student as central to the learning process. Some preservice science preparation institutions recognize that "elementary teachers need opportunities to engage with science content in investigative ways and to reflect on scientific ways of exploring science so that these methods can be used in the classroom."[30] One respondent to the Texas Survey recognized that "content is important, but presentation of content is critical for K-6." Yet another suggested that "one must incorporate many activities into their lessons to see how easy it is to integrate science into other subject areas."[31]

According to the Texas Survey, a change in the pedagogical practices of higher education is a necessary condition for changing the pedagogical practices in the public schools. In institutions of higher education, two-and four-year college professors can model exemplary science pedagogy and science curriculum practices incorporating instructional strategies of investigation and inquiry. Science teacher educators can explore nontraditional innovative methods for delivering science content and pedagogy.

- **Appropriate assessments are designed to provide analytical, suggestive** and informative feedback to all students.

> Sheer imitation, dictation of steps to be taken and mechanical drill, may give results more quickly and yet strengthen traits likely to be fatal to reflective power.[32]

Not only is it important to tailor instructional strategies to enhance science learning for diverse groups of learners; it is also important to design appropriate analytical, helpful, and informative assessments. John Dewey reminds us that simply dictating "right answers" for drill-and-kill exercises does not give informative feedback to students about their learning in science — and may actually impede the development of reflective, analytical thinking. In order for this type of learning to occur, assessment strategies are carefully crafted to match and inform instruction. Instruction and assessment are two sides of the same coin that focuses on student learning of important concepts in science and on science as a way of knowing.[33]

All science teachers engage in ongoing assessment of their teaching and student learning by using multiple methods and systematically gathering data about student understanding and ability. Teachers select, create, and use assessment strategies that support the development of student understanding and nurture a community of science learners. Assessment can be done in many different ways. Besides conventional paper-and-pencil tests, assessments might include performances, portfolios, investigative reports, and written essays.[34] Assessments need to be developmentally appropriate, set in contexts familiar to students, and as free from bias as possible. Assessment strategies, if used systematically, will gather data on student understanding and

ability over time. Science teachers can use this information about their students to guide their teaching.

One frustrated university student offers his point of view regarding the failure of his university courses to inspire critical thinking and problem solving skills and therefore adequately assess his knowledge regarding the subject matter.

In high school, my teachers made sure everyone knew that book learning was not going to help us in college. If we hoped to succeed in higher education, our minds would have to develop beyond the regurgitation mode. However, universities have failed to encourage our intellectual development by mandating huge lecture classes whose only criteria for passing is to make sure that the textbook has been read, formulas have been memorized and the "plug and chug" formula can be followed.[36]

It is important to acknowledge that effective science learning, like other disciplines of learning by students, requires feedback. Simply repeating tasks and procedures or memorizing the elements on the periodic table of elements is unlikely to bring about thoughtful understanding. Real learning most often takes place when students have opportunities to express ideas and get feedback from their peers. Feedback that is most helpful to learners consists of more than the provision of correct answers. Feedback that is analytical or suggestive, comes at a time when students are interested in it and allows time for students to reflect, make adjustments and to try again is a requirement that is neglected by most examinations—especially final examinations.[35] Understanding the purposes of their own learning and formulating self-assessment strategies are important components of student-centered teaching.

What do Texas institutions that prepare teachers say in regard to new forms of assessment? Noteworthy from the data gathered from the Texas Survey is the number of respondents who indicated the need for more information on alternative assessment. While there were no respondents from public institutions that indicated this need, there were nine respondents that indicated an awareness only of general principles.[37] Effective teachers of science know and apply the necessary safety regulations in the storage, use, and care of science material and organisms used by students. Effective teachers also teach students the importance of safety in scientific investigations and reinforce responsible practice on a regular basis.

An exemplary first grade teacher makes this statement about the physical learning environment for effective science teaching.

The problem with science is that it needs space, storage for materials and money to buy the material. It's a lot of work to prepare . . . and some people don't want to bother with it. It's hard work.[38]

Physically stimulating science learning environments are not limited to the classroom.

> An outstanding elementary science presidential awardee shares a worthwhile inservice experience that occurred in *the field*, rather than in the classroom learning environment.
>
> *When I received that NSF Fellowship at Sam Houston State [I had] the very best college professors, . . . they took us out in the field and I learned about paleontology, rock strata, . . . marine science as well as astronomy. I learned how to use a planetarium, and then go out in the field and identify constellations.*[40]

local rivers, caves, airports, zoos, power plants, archeological sites, parks, and botanical gardens. Many communities have access to science centers, museums, national laboratories, and industry.[39] These rich in-the-field environments offer tremendous resources to teachers and students of science.

It is important to point out that an integral part of the learner-centered community is that the teacher views differences as opportunities for learning and cross-cultural experiences. It is the teacher who establishes a relationship between the curriculum and community cultures. While making this connection, the teacher and students explore attitudes that foster unity. As a result, the teacher creates an environment in which learners work cooperatively and purposefully, using a variety of resources to understand themselves, their immediate community, and the global society in which they live.[41] A stimulating, democratic, safe, and respectful social environment is conducive to effective learning in science.

Besides physical safety, the emotional learning environment for student-centered instruction must be safe. It should be risk free. Students need to feel comfortable sharing ideas and insights about science and science investigations. This comfort is nurtured through an environment that is warm, inviting, friendly, respectful, and intellectually challenging. An intellectual learning environment invites and encourages self expression where students feel comfortable learning and sharing ideas, insights, and experiences. Students should also be invited to contribute their ideas about the learning environment. Discussions about how to use time and space for work challenge students to take the responsibility for their learning. With this sharing comes the responsibility of care of space and resources. As students pursue their inquiries, they need access to resources and a voice in determining what is needed.[42]

Conclusion

Current interest at the national level on reform in undergraduate science education confirms the role of undergraduate science education as a critical piece of the puzzle of building effective science education programs and achieving science literacy for all students. Student-centered teaching and learning at the undergraduate level is linked to student-centered teaching

An outstanding elementary science teacher demonstrates her willingness to nurture her students' curiosity about a bean seed. She describes the adjustment she makes during a mathematics lesson to encourage student investigation of a question about a bean seed.

We were doing story problems for math. I meticulously decorated beans to look like people to use as sorting tools for some equation writing. One of my students anxiously raised his hand and said, "Ooh, Ms. G., look! The skin on the outside of my bean is cracking, is it going to sprout?" Well, you can't just totally dump your math lesson; but, it's worth it to take a few minutes to steer kids in the direction of some library references to find out how long it might take before the bean actually sprouts.[43]

and learning at all other levels. A change in undergraduate instruction can improve college students' understanding of essential science concepts and at the same time provide appropriate instructional models for future teachers.

> Undergraduate SME&T [science, mathematics, engineering, and technology] education depends on the students who come from grades K-12, relies on faculty who come out of graduate programs, and prepares teachers for the K-12 system and students for graduate school. The kinds of programs offered for graduate students have significant implications for the future of undergraduate education; the professional standard adopted for student learning in grades K-12 impact undergraduate education as well. So, these sectors have mutual obligations to each other, and the fulfillment of these obligations is essential for the health of the whole.[44]

Research results on K-12 student learning recently summarized by Dorothy Gabel[45] parallel the findings of the growing group of faculty involved in projects supporting reform in the undergraduate arena.[46, 47] All student-centered teaching and learning strategies have one thing in common: they keep the students' attention focused on learning.

> Whether it is done by pausing after asking a question before calling on a student to answer (wait time), by involving students in decision making (computer simulations), or by having students compare new concepts to familiar situations (using analogies), all of these strategies require active learning. Many involve creating situations that challenge students' assumptions by having them make observations that are in conflict with their beliefs (cognitive conflict), and then resolving the conflict. When instruction involves topics that interest students and is related to their world, students learn in more authentic ways. That is, they see the relationship between what they are learning and what they already know; they think instead of memorize.[48]

A student's primary learning style determines how he or she perceives, interacts with, and responds to his or her learning environment. Whatever the similarities and differences in the learning styles and intelligence of the students, all teachers of science can help their students learn. Effective teachers of science employ their knowledge of current theories of teaching and learning, use a range of active learning approaches and varied teaching techniques and strategies, and design assessments that inform both teaching and learning processes. These components of the student-centered approach when effectively integrated into the structure of the physical, social, and intellectual learning environment of the student create optimal conditions for teaching as well as for learning.

Questions to Consider

1. As national and state standards for science are implemented in K-12 education, should institutions of higher education individually or collectively develop similar standards that reflect expected outcomes of undergraduate science education?
2. Which is more important for future teachers of science — breadth or depth —in science conceptual understanding?
3. What kind of faculty rewards and departmental incentives are needed to drive reform in science education at the undergraduate level?
4. What institutional changes are needed to make student-centered learning and teaching more central and important in undergraduate education?
5. How can the quality of learning be improved in an age of seriously constrained resources?

Endnotes

[1]V. Dadydov, "The Influence of L. S. Vygotsky on Education. Theory, Research, and Practice." *Educational Researcher* 24.3 (1995) 17.

[2]Davydov 17.

[3]National Research Council, *National Science Education Standards* (Washington: National Academy Press, 1996) 62.

[4]*National Science Education Standards* 62.

[5]Senta A. Raizen and Arie M. Michelsohn, *The Future of Science in the Elementary Schools: Education Prospective Teachers* (San Francisco: Jossey-Bass, 1993) 82.

[6]*National Science Education Standards* 62.

[7]American Association for the Advancement of Science, *Science for All Americans* (Washington, AAAS, 1989) 201.

[8]*National Science Education Standards* 63.

[9]Texas Education Agency, *Learner-Centered Schools for Texas: A Vision of Texas Educators* (Austin: TEA, 1995) 6.

[10]Jaqueline Brooks and Martin Brooks, *In Search of Understanding: The Case for Constructivist Classrooms* (Alexandria: Association for Supervision and Curriculum Development, 1993) 4.

[11]Brooks and Brooks 121.

[12]Rodger W. Bybee, *Reforming Science Education: Social Perspectives and Personal Reflections* (New York: Teachers College Press, 1993) 110.

[13]Davydov 17.

[14]Andrea Foster, "Interviews of Elementary Science Presidential Awardees: Patterns that Portray Excellence in Science Teaching," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996) 8.

[15]Raizen and Michelsohn 86.

[16]Foster 14.

[17]Dawn Parker, "Preservice Elementary Science Survey: A Description of Programs at Colleges and Universities in Texas," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996) 17.

[18]*National Science Education Standards* 31.

[19]Texas Education Agency 6.

[20]*National Science Education Standards* 32.

[21]*National Science Education Standards* 32.

[22]Raizen and Michelsohn 80.

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[23]Foster 51.

[24]Foster 52.

[25]Parker 31.

[26]*National Science Education Standards* 44.

[27]Parker 31.

[28]David Jonassen, *Computers in the Classroom: Mindtools for Critical Thinking* (Columbus, OH: Prentice Hall, 1996).

[29]Jonassen 10.

[30]Parker 29.

[31]Parker 30.

[32]John Dewey, *How We Think* (New York: Prometheus Books, 1991) 51.

[33]Raizen and Michelsohn 82.

[34]S. Loucks-Horsley, R. Kapitan, M. Carlson, P. Kuerbis, R. Clark, G. Marge Nelle, T. Sachse, and W. Walton, *Elementary School Science for the 90's* (Massachusetts: The Network, 1990) 93.

[35]*Science for All Americans* 199-200.

[36]Kieran Watson, "Verbal Exams Force Understanding," *The Battalion* 4.18 (1996) 5.

[37]Parker 12.

[38]Foster 54.

[39]*National Science Education Standards* 45.

[40]Foster 28.

[41]Texas Education Agency 6.

[42]*National Science Education Standards* 45.

[43]Foster 14.

[44]National Science Foundation, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology* (Washington: NSF, 1996) i.

[45]Educational Research Service, *Improving Student Achievement in Science* (Arlington, VA: ERS, 1996) 4.

[46]*Shaping the Future* 17-18.

[47]National Research Council, *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Washington: National Academy Press, 1966) 22.

[48]Educational Research Service 4.

Inquiry-Based Teaching and Learning

Scientific inquiry forms the core of science teaching and learning experience for students at all levels.

This happens when

- Learning experiences provide time for students to develop deep conceptual understandings about science through the integration of content and process in contexts that encourage investigation, debate, and argument.
- Learning experiences provide opportunities for students to develop, use, and balance their innate qualities of curiosity, openness, and skepticism.
- Learning expectations regarding scientific inquiry and investigation are reflected in assessment practices.
- Reflective practice is valued by both teachers and learners as an integral part of the teaching and learning process.

On Inquiry, Inquiry Teaching, and Investigation

The *National Science Education Standards* state that "inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning and conducting investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions, and communicating the results."[1]

Inquiry is at the heart of the scientific endeavor. The process of inquiry is modeled on the scientist's method of discovery, viewing science as a constructed set of theories and ideas based on the physical world, rather than as a collection of irrefutable, disconnected facts.[2] Inquiry is a complex process—more subtle and demanding then organizing data and more flexible than a "rigid set of steps commonly depicted in textbooks as the scientific method."[3]

> Once people gain a good sense of how science operates—along with a basic inventory of key science concepts as a basis for learning more later—they can follow the science adventure story as it plays out during their lifetimes.[4]

Inquiry teaching leads students through the experience of scientific inquiry. Students develop their understanding of fundamental scientific ideas by directly experiencing materials,

One exemplary elementary science teacher describes her thinking about beginning an inquiry experience for her kindergarten students. In this example, she explains that inquiry teaching involves helping students develop significant questions.

I'm not a teacher that says, "OK, what would you like to learn about, go with it." Because I feel like you've got to give them something to go [on] to ask the right questions. If I give them a squid dissection experience, and they start looking at the arms and the tentacles and the difference in those things, then they relate that to another animal in some way and they are going to have a better basis to go on with their own research. But if I start a unit and say, "OK, we are doing the ocean, what do you want to learn about?" they can come up with some pretty superficial stuff.[5]

consulting resources that include experts, and discussing among themselves. Inquiry teaching requires students to organize prior knowledge with new science knowledge and skills via their innate qualities of curiosity, openness, and skepticism. Inquiry teaching requires highly skilled teachers knowledgeable about scientific content and pedagogy who can structure learning experiences that challenge students to formulate and ask questions, to shape their own learning through debate with themselves and others.

Introductory statements in the *Texas Essential Knowledge and Skills in Science (TEKS)* state, "*Investigations* are used to learn about the natural world. Students should understand that certain types of questions can be answered by investigations, and that methods, models, and conclusions built from these investigations change as new observations are made. Models of objects and events are tools for understanding the natural world and can show how systems work. They have limitations and based on new discoveries are constantly being modified to more closely reflect the natural world."[6] This introductory statement describing *investigation* precedes more specific statements about what students must know and be able to do as a result of their science learning experiences at each grade level. The first three *TEKS* at all grade levels specifically address scientific process in the terms of investigation and scientific inquiry in this form:

> **Scientific processes.** The student conducts field and laboratory investigations using safe, environmentally appropriate, and ethical practices.
>
> **Scientific processes.** The student uses scientific inquiry methods during field and laboratory investigations.
>
> **Scientific processes.** The student uses critical thinking and scientific problem solving to make informed decisions.[7]

The Texas Essential Knowlege and Skills, like other current inquiry-based science reform efforts, focus on instruction that allows students to develop an understanding of basic science

concepts while learning through the process of scientific inquiry. There is a balance of content and process in inquiry-based science, with teachers making decisions regarding the character of their classrooms based on the diversity and needs of their students, communities, and school systems.[8] This approach to teaching science has serious implications for the preparation of elementary teachers. Preservice teachers' needs in this area are many. They need experience in framing questions, designing research approaches, conducting investigations, and responding to critical analysis; they also need to develop an understanding of what inquiry teaching is; and they must learn to structure learning experiences that allow their students to conduct investigations in order to learn about the natural world.

- **Learning experiences provide time for students to develop deep conceptual understandings about science through the integration of content and process in contexts that encourage investigation, debate, and argument.**

Current research suggests that the preservice teachers tend to believe that learning is "absorbing" and teaching is "telling and assessing." These beliefs are strongly entrenched and make teacher education difficult. To alter these resilient beliefs, teachers must be *provoked* to question their own past experiences and to question the beliefs inherent in those experiences.[9] Inquiry-based courses will challenge these beliefs.

> Teachers of science will be the representatives of the science community in their classrooms, and they form much of their image of science through the science courses that they take in college. If that image is to reflect the nature of science as presented in these standards, prospective and practicing teachers must take science courses in which they learn science through inquiry, having the same opportunities as their students will have to develop understanding.[10]

Research indicates that college and university level science courses require extensive change to prepare elementary teachers for new science curriculum reform.[11] One successful teaching approach is to present science learning as *problems to solve* rather than *facts to memorize*, changing the focus away from the traditional abstract, rudimentary, inert packets of scientific knowledge that are presented out of context. Such a scenario was posed in recent *Proceedings* of a National Science Foundation workshop.

> What if science learning were packaged into some sort of "situated learning problem" that required students to plan, prepare, design, execute, and evaluate their own solutions to a practical problem that incorporated the learning of science into its solution? What if science knowledge were assumed to be an essential component of preparation for the problem solution, rather than the product of the problem itself? . . . What if reflection were viewed as a personal, individualized product of an integrative, synthetic, constructivist process: the product of an individual's "making sense" of all aspects of the problem, including the development of new understandings about science within situated, real-world

The expertise with which an exemplary elementary teacher implements a teacher-directed inquiry lesson is demonstrated by the following instructional sequence, described in the teacher's own words. This sequence demonstrates a chalk-talk to encourage and guide students' questions as they begin to study sharks.

Today, we began sharks and basically I did a talk-through draw lesson on the board. I drew the basic body shape without any fins and I had them predict what it was going to be. (We had already done fish.) They say, "Torpedo shaped body. This could be a tuna..." One of the kids said, "With the placement of the mouth where it is, I'll bet it is a shark." I said, "OK, tell me more about what I need to add to it." So we start drawing and adding and changing and I start talking about different fin lengths and the lopsided tail fin and how you could tell by the fin what shark it was. Then we started comparing it to the fish and [wondering] what other things do the fish have that this would need, and that would be gills. Well, sharks really have gills but they don't have an operculum and it's a different kind of structure, so we talked about the 5-6-7 gilled shark and the time periods when you were to have found those. So, it was just a real talk through lesson as we were drawing.

At this table, I had a big jug of water [holding] a clear film canister with a weight in it. I also had a canister filled with water and I had one filled with oil. The one with air in it represented the swim bladder which makes the fish very buoyant. If you don't have that you sink totally; the oil put him somewhere in between. So the shark has some buoyancy but not the buoyancy control that a fish has. And so we used that to demonstrate.[14]

contexts? And what if a new assessment strategy, such as performance portfolio, were employed to assist, monitor, and guide not only the learning of students but the teaching of the instructor? And finally, what if the teaching and learning environment for non-science majors also provided a safe research environment for all to learn more about the processes of teaching and learning science?[12]

Instructional strategies that encourage inquiry have two significant learning outcomes: first, students experience inquiry as being at the heart of what is to be learned in the science classroom; and second, students who will become teachers experience science as it should be taught in their own classrooms. *Science Teaching Reconsidered* reviews many non-traditional approaches that support inquiry-based teaching, including collaborative learning, small group discussion, posing questions during lecture, and incorporation of inquiry-based field and laboratory experiences.[13] All of these approaches have a similar goal: to engage the student in science learning experiences as an active participant in his or her own sense-making while keeping the students' attention focused on learning. These approaches also require careful thought and design in their implementation to bring about the goal.

Small group discussions, even in large-enrollment courses, can encourage inquiry learning through debate and argument. Discussions, unlike lecture, encourage active student participation. Focused discussions, which require students to prepare before class,

are effective for many students in developing their conceptual frameworks and learning problem-solving skills as they try out their own ideas on other students and the instructor.[15] *Science Teaching Reconsidered* provides helpful hints to college instructors who may not be aware of the values of discussion in their science classes.

> The give and take of technical discussion also sharpens critical and quantitative thinking skills. Classes in which students must participate in discussion force them to go beyond merely plugging numbers into formulas or memorizing terms. They must learn to explain in their own words what they are thinking and doing... Sensitivity to personality, cultural, linguistic, and gender differences that may affect students' participation is also important, especially if participation is graded. ...You might try various strategies to engage your students in meaningful discussion by posing questions that measure different levels of understanding (knowledge, application, analysis, and comprehension).[16]

In large lecture sections, instructors can also encourage inquiry learning by **posing questions during lecture**. Employing wait time, which provides students with enough time to formulate an opinion or answer with confidence, increases students' participation.[17] An instructor's questions can build confidence when students are encouraged to propose several different answers to a question. Students can then be encouraged to step outside the answers and begin to develop the skills necessary to assess the answers. Questions discourage inquiry thinking when they seek factual information and measure student recall. Questions encourage inquiry thinking when they require a student to elaborate on or explain a concept, to compare and contrast several possibilities, or to speculate about an outcome or about cause and effect. The type of question asked and the response given to students' initial answers are crucial to the types of reasoning processes the students are encouraged to use.[18]

An exemplary teacher explains how a video sequence can be used to introduce a lesson.

I used a video sequence with the kids before the squid dissection. I mean if you have ever seen a squid sitting on a plate, which I know you have, it is not an exciting looking creature. But, if you have ever watched it move! They are so beautiful and so full of life. They are incredible. Then I showed them another sequence which is a 3-second clip from Oceans Alive that actually shows the squid using tentacles to grab the prey and then pull it in eating it. It's that fast. And I play it. Replay it. [Then I say], "OK, tell me what you observe. Tell me why there is a difference in these two. Why are there tentacles and arms? Why aren't there ten arms?" Based on that, instead of me telling them, we look at the squid and then we figure out the structure.[19]

Demonstrations can also be carefully structured to encourage inquiry learning. Careful attention must be given to engaging students by provoking them to think for themselves, to challenge an assumption or misconception, or illustrate an otherwise

abstract concept. *Science Teaching Reconsidered* suggests demonstrations using everyday objects in which students are asked to make predictions or vote on the most probable outcome.

Collaborative learning is an umbrella term used for a variety of educational approaches that involve joint intellectual effort by students, or by students and teachers together. In these approaches, students work in groups to achieve a common goal. For example, a group of students might be assigned to work together to design a solution to a problem or make an informed decision about a controversial issue. Carefully constructed collaborative learning problems can encourage students to be creative, to argue and defend their positions, to support their positions with outside resources, and to seek resolutions to differences which may develop within the group. Additional concern needs to focus on the collaborative nature of scientific inquiry.

> Some aspects of inquiry are individual efforts, but many are not, and teachers need to experience the value of benefits of cooperative work as well as the struggles and tensions that it can provide.[20]

Research findings regarding the effectiveness of collaborative learning in public school settings have been quite favorable in terms of student outcomes. These findings have stimulated the design of a number of studies exploring the effectiveness of collaborative learning in university settings. Potential problems have been identified regarding implementation of collaborative/cooperative models at the university level, including coverage of material, lack of control during class, students who do not carry their weight in a group, and evaluation of group participation. However, several university reform projects report that collaborative work enhances student achievement and motivation in mathematics and science learning contexts.

Finally, **effective laboratory and field experiences** can encourage inquiry learning. Developing an effective laboratory requires appropriate space and equipment and extraordinary effort from instructors in gathering and organizing materials. In the laboratory setting, computers can enhance data acquisition and analysis and thus allow students to think conceptually about the patterns arising from the data. Effective instructors circulate among students to pose and answer questions, point out subtle details or possible extensions, and unobtrusively guide their students' learning. Worksheets, all too common in the traditional science laboratory, can be replaced with handouts that pose carefully constructed questions that require students to formulate, test, and reconceptualize their learning.[21] In a similar fashion, field trips can provide contexts for inquiry-based learning among students interacting cooperatively to solve problems posed by the instructor that require students to observe, infer, and make conclusions on the basis of their prior knowledge and/or use of resources. Field trips might include a tour of a local landfill, a field hike on a disturbed prairie habitat, or a behind-the-scenes tour of a zoo or aquarium. Carefully structured out-of-class experiences can provide the science student with

real-world experiences that can be replicated in non-structured environments.

In any inquiry-based approach, there is a balance of content and process, but teachers of science who hold these values may differ in their methods.[23] The character of each inquiry-based classroom emerges from the decision of the teacher, who is the only one capable of understanding the constraints of time and materials as well as the needs of the learners and the communities they represent. "Educators must first understand their own values and engage in their own inquiry to develop a deep understanding of their communities' needs for rich, vital science education."[24]

- **Learning experiences provide opportunities for students to develop, use, and balance their innate qualities of curiosity, openness, and skepticism.**

In the new vision of science literacy, inquiry is a step beyond "science as a process" in which students learn skills, such as observation, inference, and experimentation. While new visions of inquiry, inquiry teaching, and investigation include the "processes of science," they are not treated as separate skills to be learned. The new vision requires students to incorporate processes and scientific knowledge with scientific reasoning and critical thinking to develop their understanding of science. Students who are engaged in inquiry develop deeper understandings of science including an appreciation of "how we know" what we know in science, skills necessary to become independent inquirers about the natural world, and the dispositions to use the skills, abilities, and attitudes associated with science.[25]

Science for All Americans calls the values, attitudes, and skills associated with science, mathematics, and technology *habits of mind* because they relate directly to a person's outlook on knowledge and learning and ways of thinking and acting.[26] The *Guidelines* identify *innate qualities*, with much the same meaning. These innate qualities underlie the processes of inquiry

> A kindergarten presidential awardee shared a meaningful experience she had at a teacher institute in Port Aransas. She was particularly impressed by the leader's teaching. She made this suggestion about how to change preservice teacher education:
>
> *I think you are going to have to get preservice teachers out in field situations. That's when teachers get excited. We took teams of teachers who represented each grade level down to Port Aransas for a solid week. They were involved with intensive field work followed up with, "Here's what you do in the classroom." It was hours of field work. Those teachers come back so fired up and it wasn't from sitting and doing classroom work. It was from being on the beach and seeing relationships that could be translated to the classroom.*[22]
>
> She went on to explain her ideas regarding field experience in elementary science education. She suggested that a geology content course might be coupled with an elementary school field experience by combining the work with the geology professor and " work with kids on the nature trail."[23]

by stimulating the human mind to find out more, to be certain, but also to doubt. The *Benchmarks* recommend that as early as the end of the second grade students should

> raise questions about the world around them and be willing to seek answers to some of them by making careful observations and trying things out.[27]

In grades 3 through 5, students should "also sometimes think up and propose explanations for their findings."[28] The *Benchmarks* state that the main point to stress is that for any given collection of evidence it is usually possible to invent different explanations, and it is not always easy to tell which will prove to be the best. By the end of the 5th grade students should

> keep records of their investigations and observations and not change the records later, and offer reasons for their findings and consider reasons suggested by others.[29]

The *Benchmarks* also warn that care should be taken in grades 6 through 8 to continue to foster curiosity. "Time needs to be found to enable students to pursue scientific questions that truly interest them. Inquiry projects, individual and group, provide that opportunity. Such projects also establish the importance of scientific honesty in describing procedures, recording data, drawing conclusions, and reporting conclusions."[30] The *Benchmarks* recommend, for example, that by the end of 8th grade students should

> know that hypotheses are valuable, even if they turn out not to be true, if they lead to fruitful investigations.[31]

Skills and attitudes develop over time. References such as these from the *Benchmarks* indicate changes in sophistication and complexity throughout the learner's public school science experiences. By the end of the twelfth grade, the *Benchmarks* suggest that students should know why curiosity, openness, and skepticism are so highly regarded in science and how they are incorporated into the way that science is carried out.[32] Twelfth graders should exhibit those traits in their own lives and value them in the lives of others. Moreover, they should view science and technology thoughtfully, being neither categorically antagonistic or uncritically positive.

> One manifestation of such inclination is what someone thinks about when reading news articles. For example, on reading that trees were being logged for an important new drug found in their bark, the science-literate person might wonder about the yield from a single tree, the amount of drug needed, how long a new tree would take to grow, or about the possibility of synthesizing the drug instead, or about what species in the forest might suffer from the loss of those particular trees; or about how complex ecological interactions are and the need for computer software to track the implications, or about possible bias in whoever was responsible for considering those various possibilities.[33]

Implications for preservice teacher preparation are obvious. Students at every grade level and in every domain of science should have the opportunity to use scientific inquiry.[34] Elementary teachers should be able to design learning experiences that support student investigation and enhance the development of th..se innate qualities. This implies a radical change in the elementary teacher's concept of what it means to be a teacher of science. Inquiry, inquiry teaching, and investigation occur in learning environments that are open to new ideas, encourage skepticism, and foster curiosity in students.

An exemplary teacher of kindergarten students talks about nurturing students' inquiry skills.
It's learning to look at things in a new way. And that's what a scientist does. Because if they always look at it a traditional way, they are going to miss something. They have to figure out a different way to look at it. A different way to set up the problem to see if they come up with the same results. So, I think we need to model that kind of thing in our classroom.
She continues with a specific example.
For teaching classification, generally what I have seen are dichotomous trees or whatever, where there is one way to do it. Well, that's not the way we do it. We do it one way and then we put it all back in the middle and say, "OK, we did it that way; can you figure out a different way to do it?" And so we will go through and do it some other way. When we were doing some simple dichotomous sorting with Halloween candy, the kids came up with 29 different ways to sort their candy. They all want to contribute.[35]

The *National Science Education Standards* present science teaching standards in the first chapter. These standards reflect the complex interrelationships existing among inquiry, inquiry teaching, scientific investigation, and the innate qualities of curiosity, openness, and skepticism. In learning environments where teachers guide, focus, challenge, and encourage student learning— curiosity, openness and skepticism are also encouraged.[36] The *Standards* suggest that teachers and students collaborate in the pursuit of ideas in successful classrooms, with students initiating new activities related to an inquiry. Teachers become skilled inquiry teachers when they are able to match their actions to the particular needs of the students and are able to decide when and how to guide, when to provide information and particular tools, and when to connect students with other sources.

Implementing the recommendations to the *Teaching Standards* requires a range of actions based on careful assessment of students, knowledge of science, and a repertoire of science-teaching strategies. The *Standards* warn, however, that one aspect of the teacher's role is less tangible; teachers are models for the students they teach. A teacher who engages in inquiry with students, models the skills needed for inquiry. Effective teachers exhibit enthusiasm and interest. Those who speak to the power and beauty of scientific understanding instill in their

students some of those same attitudes towards science. These teachers "encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas, and skepticism that characterize science."[37]

- **Learning expectations regarding scientific inquiry and investigations are reflected in assessment practices.**

The *National Science Education Standards* state that "the assessment process is an effective tool for communicating the expectations of the science education system to all concerned with science education."[38] The *Standards* view assessment as the primary feedback mechanism in the science education system.

> In this new view, assessment and learning are two sides of the same coin. The methods used to collect educational data define in measurable terms what teachers should teach and what students should learn. And when students engage in an assessment exercise, they should learn from it. ...all aspects of science achievement—ability to inquire, scientific understanding of the natural world, understanding of the nature and utility of science—are measured using multiple methods such as performances and portfolios, as well as conventional paper and pencil tests.[39]

The standards for assessment presented in the *National Science Education Standards* were written to be applied equally to the assessment of students, teachers, and programs, to classroom assessments as well as large-scale, external assessments, for both summative and formative purposes. New interest in the assessment of learning and contemporary views of measurement theory and practice challenge inquiry-based teachers to think of students' assessment as resulting in much more information than a terminal "grade" representing a particular level of achievement. New assessments inform students as to how well they are progressing in terms of understanding and integrating scientific content and process; they also inform teachers as to how well they are facilitating the learning process. New assessments are carefully crafted feedback systems that inform, correct, and improve student learning.

The *Texas Essential Knowledge and Skill in Science (TEKS)* define the science that all students will come to understand. Listed in two-column format, the TEKS specify through Essential Knowledge (EK) statements that the students should know and through Student Expectation (SE) statements that the students should be able to do with that knowledge. Content (EK) and process (SE) are linked. The *TEKS* provide a wide range of content and process standards across and among grade levels, which are both horizontally and vertically articulated to assure that student expectations by grade are developmentally appropriate and that they also change in depth and complexity with the age of the child. The *TEKS* provide a framework for employing a wide variety of creative approaches in assessing how well and to what degree students, teachers, and science education programs are meeting the new science standards.

The *Texas Essential Knowledge and Skills in Science* portray the outcomes of K-12 science education as encompassing scientific process in students' abilities to conduct field and laboratory investigations that are safe, environmentally appropriate, and ethical; to use scientific methods during field and laboratory investigations; and to use critical thinking and scientific problem solving to make informed decisions. Specific student expectations not only guide the choice of appropriate learning experiences but also the design of appropriate assessments. For example, in grade 4 the student is expected to construct simple graphs, tables, maps, and charts to organize, examine and evaluate information.[40] The implication is that learning experiences as well as assessment practices will inform both teacher and student regarding the students' ability to represent organized, examined, and evaluated information visually. The new *TEKS* highlight the complexity of both instructional and assessment processes while stressing the importance of collecting data on much more than what a student can memorize for a test. The *TEKS* imply a new way of thinking about teaching that places the student at the center of the instructional/assessment process; what the student knows and is able to do as reflected in the assessment is also a direct reflection of what the student has done in the classroom. The new *TEKS* imply that "active"—rather than "inert"—knowledge, knowledge that is connected to process and well-structured in context, is measured.

> One exemplary elementary teacher describes a group science project that involves the design and production of a car.
>
> *It is important that [your students] know you are considering the total [quality] product. I thought, if it works in business, it has to work in here. So we divided into teams. Because that way everybody doesn't write me a report about [something]. They get together and say, "I found this," and "I found this." "OK, let's write these down." Then one student writes it up. Somebody else is the reporter and they go over and type it up on the computer. And then they call for the two people that are trained to come up and print it and that person comes and punches in and prints it for them. So, they only bring me the finished product, a nice typed up report of what they found out from their library research... and the whole team comes together to present it to me. One person has typed it, but they have all collaborated on this.*[41]

Assessment of active knowledge can take many forms, some of which are indistinguishable from the learning process. Assessments can be individual or group, or a combination of both. Such activities as interviews, formal performance tasks, portfolios, investigative projects, written reports, multiple choice, short answer, and essay examinations are appropriate assessments when they are chosen to match the learning goals. However, the *Standards* warn that the relationship of some of these forms of assessment tasks to the learning goals of the science program may not be as obvious as others.

> For instance, a student's ability to obtain and evaluate scientific information might be measured using a short-answer test to identify the sources of high-quality scientific information about toxic waste. an alternative and more authentic method is to ask the student to locate such information and develop an annotated bibliography and a judgment about the scientific quality of the information.[42]

New recommendations for assessment mirror the new vision for science education based on inquiry, inquiry teaching, and scientific investigation. They recommend more emphasis on assessing what is most highly valued; assessing rich, well-structured knowledge, and assessing scientific understanding and reasoning. Assessment is viewed as an ongoing process that informs both teacher and students about their areas of strengths and weaknesses in the complex enterprise of teaching and learning.

Effective preservice elementary science preparation programs will provide multiple opportunities for students to experience, understand, and later be involved in designing assessments that accurately reflect the learning goals of their science and science methods classes. New teachers will understand reasons for the linkages between content and process that are shown in the *Texas Essential Knowledge and Skills in Science*, and transfer of these understandings will occur in the elementary classrooms of Texas. Elementary teachers must understand the relationships among science content and process, as well as between teaching, learning, and assessment. Assessment methods must be aligned with the learning that occurs in inquiry-based contexts that encourage investigation, debate, and argument.

- **Reflective practice is valued by both teachers and learners as an integral part of their becoming lifelong learners.**

"Continuous learning is an active process that requires different norms from those that are presently operative in colleges and in schools: norms of experimentation and risk-taking, of trust and collegial support, and, most relevant to science of careful and dedicated inquiry."[43] Learning for all of us is a developmental process that takes time and often is hard work. A critical part of learning is reflection, when the learner confronts his or her successes and challenges during the learning process. Individual and group reflection in either structured or unstructured settings provides an opportunity for learners, and particularly inquiry learners, to set personal goals and take responsibility for their own learning.

Self-reflection is an art to be developed over time. The *Benchmarks* suggest that kindergarten through second grade is the ideal time for students to begin to reflect on their own learning. "They should be encouraged to notice how they learn by asking them how they learned something in the past or how they might learn to do something new or by having them teach a skill to someone else."[44] By the end of the second grade, students should know that "people can learn from each other by telling and listening, showing and watching, and imitating

what others do."[45] The *Benchmarks* further explain that children's self-awareness increases in grades 3 through 5, and it is at this critical period that they want to know more about their own personal capabilities and what they might be able to do and know. A related benchmark for 5th grade is that students should know that "human beings can use the memory of their past experiences to make judgments about new situations;"[46] as well as that:

> "Learning means using what one already knows to make sense out of new experiences or information, not just storing the new information in one's head."[47]

In grades 9 through 12, the *Benchmarks* further explain, students can reflect on and generalize from the particular studies in previous grades. By the end of 12th grade, students should recognize that "the context in which something is learned may limit the contexts in which the learning can be used."[48]

Many techniques to encourage learning reflection are available, and their use is becoming more widespread. Teachers of science often require their students to keep reflective journals, which record students' perceptions, questions, and concerns about what they are learning while they are learning it. Portfolios can be structured to require students to reflect on their most successful learning experience, to track their learning over time, to take some time out of class to analyze their progress, and to identify for themselves what they may need for further learning. Short formative self-assessments at the end of each learning week may provide students with reflective expertise. Simple questions such as the following stimulate students to reflect back on prior experience, to make sense of prior learning, and to assess their own abilities and concerns in their learning:

> "What was the most important thing you learned in science this week?"
>
> "What was the most difficult task that you had to do in science this week?"
>
> "What would you do differently in science class this week if you could do it over again?"

Teacher learning is analogous to student learning: Learning to teach science requires that the teacher articulate questions, pursue answers to those questions, interpret information gathered, propose applications, and fit the new learning into the larger picture of science teaching.[49] As the primary job of the teacher is to promote learning, it naturally follows that teachers themselves are dedicated learners. Teaching itself is a complex process, requiring constant learning and continual reflection. new knowledge, skills, and strategies for teaching come from a variety of sources, just as new knowledge, skills and strategies in scientific inquiry come from a variety of sources. All teachers of science can learn from their own teaching. Self-reflection tools such as journals, audiotapes or videotapes, and portfolios allow teachers to

capture their teaching, track and analyze the changes that occur in their teaching over time, and identify particular challenges as they are confronted. Just as children profit from study groups in learning science, teachers themselves can profit from study groups and sharing sessions that focus on their teaching.

"Just as science is a process of discovery, so too is science teaching."[50] Inquiry-based science teacher preparation encourages teachers to appreciate the questions of science teaching as well as the questions of science. Both evoke the same processes of framing questions, designing approaches, executing trials, making conclusions, and responding to critical analysis. Teachers of science search for "best solutions" to teaching problems just as science researchers search for "best solutions" to scientific problems.

> Teachers of science constantly make decisions, such as when to change the direction of the discussion, how to engage a particular student, when to let a student pursue a particular interest, and how to use an opportunity to model scientific skills and attitudes. Teachers must struggle with the tension between guiding students toward a set of predetermined goals and allowing students to set and meet their own goals. . . . Teachers match their actions to the particular needs of the students, deciding when and how to guide—when to demand more rigorous grappling by the students, when to provide information, when to provide particular tools, and when to connect students with other sources.[51]

Reflective teaching and learning allow enhanced experiences for both teachers and students. The metacognitive process of reviewing a teaching experience or lesson maximizes the learning opportunity. According to Munby and Russell, "reflection-in-action consists of two crucial elements; *reframing*, seeing a situation in a new way as a result of unexpected messages from practice; and *new action*, a new approach to practice suggested by the reframing."[52]

An exemplary elementary teacher references the value of inquiry in her science education course work.
The most important thing I learned from my college experience in graduate school was learning how I learned. It had such an impact on me and I really learned to believe in myself and my abilities at the same time.[53]

In this regard, preservice courses can teach techniques for reflection and practicing teachers could be given opportunities to develop these skills as well. Additionally, college and university leaders could encourage excellent teaching and reward reflective teaching practice with promotion, awards, tenure, and remuneration.[54] As William Kirwan suggests in an opening remark to a National Science Foundation workshop, reform in mathematics and science education "will come to pass on the scale necessary only if universities adopt... an expanded award structure."[55]

The Texas Survey question regarding the special needs of elementary teachers and their teaching of science elicited responses about the pedagogical needs of elementary science teaching. These college and university instructors are concerned that "elementary teachers need opportunities to engage in investigative ways of exploring science so that ... [inquiry] methods can be used in the classroom;" and that "time is needed [for teachers] to play with the same ideas and concepts that they will teach children. Ideas are needed as to how to instruct children in science."[56]

Conclusion

Inquiry, inquiry teaching, investigation, reflective practice—these are components of the new vision for science education, not only in the public schools but in undergraduate classrooms as well. A large responsibility for this new vision lies not only with public school teachers, but with America's college and university teachers of science. The executive summary of *Shaping the Future* states the vision for undergraduate education. "All students have access to supportive, undergraduate education in science, mathematics, engineering, and technology [SME&T], and all students learn these subjects by direct experience with the methods and processes of inquiry."[57]

> America's SME&T faculty must actively engage those students preparing to become K-12 teachers, technicians, professional scientists, mathematicians or engineers, business or public leaders, and other types of "knowledge workers" and knowledgeable citizens. It is important to assist them in learning not only science facts but, just as important, the methods and processes of research, what scientists and engineers do, how to make informed judgments about technical matters, and how to communicate and work in teams to solve complex problems.[58]

Inquiry teaching is the vision of science education reform in America. The implementation of inquiry teaching brings significant changes in the decisions that teachers of science make about what they teach, why they teach it, and how they teach it. Inquiry-based teachers redirect their instructional focus away from the memorization of inert factual information. Their redirection calls for knowledge, courage, creativity, and reflective practice. Student-centered learning environments focus on what learners will know about science and be able to do as a result of their learning experiences. From the earliest grades through college, students who experience science in a form that engages them in the active construction of ideas and explanations as they "do science" are developing inquiry skills that will serve them for their entire lifetimes. The new vision of science learning replaces the step-by-step sequence of the scientific method with student-driven investigations that focus on asking good questions, planning and conducting investigations, gathering data with the use of equipment that extends

the senses, constructing reasonable explanations on the basis of the data, and communicating results and explanations.

Change in any one component of the complex education system in America, as well as in the state of Texas, has direct effects on other components. There has never been a time in the history of science education more critical for all teachers of science—faculty from the disciplines of science, faculty from the disciplines of education, experienced elementary teachers, and members of the informal science community—to come together.

> New knowledge, skills, and strategies for teaching come from a variety of sources—research, new materials and tools, descriptions of best practice, colleagues, supervisors, self-reflection on teaching, and reflection on the learning of students in the classroom.[59]

Learning organizations must be built that are based on the principles of inquiry, where people representing all members of the science education community continually expand their capacities to create the results they truly desire for all learners of science.

Questions to Consider

1. What types of learning experiences typify an inquiry-based curriculum?
2. How do teachers of science, who have not experienced inquiry-based learning for themselves as learners, develop inquiry-based instructional strategies?
3. Is it really possible for preservice elementary teachers to receive the experiences they will need to teach inquiry-based science during their undergraduate education?
4. Is there a way in the process of assessing students' abilities to engage in inquiry to also assess their levels of skepticism, openness, and curiosity?

Endnotes

[1]National Research Council, *National Science Education Standards* (Washington: National Academy Press, 1996) 28.

[2]National Science Foundation, *Foundations: The Challenge and Promise of K-8 Science Education Reform* (Washington, NSF, 1997) 7.

[3]American Association for the Advancement of Science, *Benchmarks for Science Literacy* (New York: Oxford UP, 1993) 3.

[4]*Benchmarks* 3.

[5]Andrea Foster, "Field Notes of Interviews of Elementary Science Presidential Awardees" (1996) 115.

[6]Texas Education Agency, *Texas Essential Knowledge and Skills in Science* (Austin: TEA, Sept.1997).

[7]*Texas Essential Knowledge and Skills in Science.*

[8]*Foundations* 9.

[9]M. M. Kennedy, *An Agenda for Research on Teacher Learning: A Special Report* (East Lansing, MI: Michigan State University, 1996).

[10]*National Science Education Standards* 61.

[11]A. B. Arons, "What Science Should We Teach?" *Proceedings of Curriculum Development for the Year 2000:" A BSCS Thirtieth Year Symposium* (Colorado Springs: BSCS, 1989); P. H. Hounshell, "Elementary Science Specialists?" *Science and Children* 24 (1987): 20-21, 157; Carol A. Kubota and R. G. Olstad, "Effects of Novelty Reducing Preparation of Exploratory Behavior and Cognitive Learning in a science Museum Setting," *Journal of Research in Science Teaching* 28 (1991): 225-234; Kenneth R. Mechling and Donna L. Oliver, "The 4th r: Science Stepchild of the Elementary Curriculum," *Principal* 62 (1983): 41-43; B. Mittlefehldt, "Changing Priorities in Elementary Science," *Curriculum Review* 24 (1985): 24, 67-69; Peggy Tilgner, "Avoiding Science in Elementary School," *Science Education* 74 (1990) 409-412.

[12]Carol L. Stuessy, "A Challenge: Employing a Model for Preservice Teacher Preparation to the Teaching and Learning of Science by Non-Science Undergraduate Students,: National Science Foundation," *Proceedings of the National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers* (Washington: NSF, 1993) 156.

[13]National Research Council, *Science Teaching Reconsidered: A Handbook* (Washington: National Academy Press, 1997).

[14]Foster, "Field Notes" 109.

[15]*Science Teaching Reconsidered* 15-16.

[16]*Science Teaching Reconsidered* 15-16.

[17]*Science Teaching Reconsidered* 12.

[18]*Science Teaching Reconsidered* 18.

[19]Foster, "Field Notes" 124.

[20]*National Science Education Standards* 61.

[21]*Science Teaching Reconsidered* 18.

[22]Andrea Foster, "Interviews of Elementary Science Presidential Awardees: Patterns that Portray Excellence in Science Teaching, " Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996) 8.

[23]*Foundations* 16.

[24]*Foundations* 16.

[25]*National Science Education Standards* 105.

[26]*Benchmarks* 281.

[27]*Benchmarks* 285.

[28]*Benchmarks* 286.

[29]*Benchmarks* 286.

[30]*Benchmarks* 286.

[31]*Benchmarks* 287.

[32]*Benchmarks* 287.

[33]*Benchmarks* 283.

[34]*National Science Education Standards* 105.

[35]Foster, "Field Notes" 78.

[36]*National Science Education Standards* 33.

[37]*National Science Education Standards* 37.

[38]*National Science Education Standards* 76.

[39]*National Science Education Standards* 76.

[40]*Texas Essential Knowledge and Skills in Science* 14.

[41]Foster, "Field Notes" 53.

[42]*National Science Education Standards* 84.

[43]*National Science Education Standards* 69.

[44]*Benchmarks* 140.

[45]*Benchmarks* 140.

[46]*Benchmarks* 140.

[47]*Benchmarks* 141.

[48]*Benchmarks* 142.

[49]*Benchmarks* 68.

[50]*National Science Education Standards* 78.

[51]Senta A. Raizen and Arie M. Michelsohn, *The Future of Science in Elementary Schools: Education Prospective Teachers* (San Francisco: Jossey-Bass, 1993) 116.

[52]H. Munby and T. Russell, "Educating the Reflective Teacher: An Essay Review of Two Books by Donald Schon," *Journal of Curriculum Studies* 21 (1989); 71-80.

[53]Foster, "Patterns" 1.

[54]Raizen and Michesohn 140.

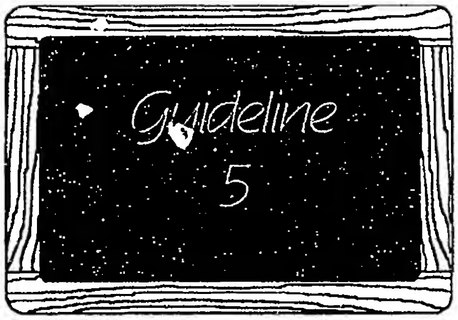
[55]William E. Kirwan. "Keynote Address: Role of Faculty in the Disciplines in Undergraduate Education of Future Teachers," *Proceedings of the National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers* (Washington: NSF, 1993) 20.

[56]Dawn Parker, "Preservice Elementary Science Survey: A Description of Programs at Colleges and Universities in Texas," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996) 29.

[57]National Science Foundation, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Washington: NSF, 1996) ii.

[58]*Shaping the Future* ii.

[59]*Benchmarks* 68.



Continuous Growth

Professional growth in science teaching is a continuous and collaborative process that begins during undergraduate preparation and extends throughout the professional careers of all teachers of science.

This happens when

- All teachers of science participate as partners in school-based experiences that provide relevant contexts for increasing their effectiveness as science teachers.
- All teachers of science use current content standards to guide their decisions about effective science teaching practices.
- All teachers of science use state-of-the-art instructional materials and equipment, including computer technology and well-equipped instructional laboratories, to support student inquiry.
- All teachers of science improve their science teaching through collegial relationships, reflective practice, and shared educational opportunities.

On Continuous Growth

Historically, learning to teach has been viewed as an experience associated with university teacher training. University classes and a semester of student teaching would fully prepare someone to be an effective teacher. The responsibilities of the university were fulfilled when the preservice teacher left with a teaching degree. More recently, professional development after the initial preparation phase has been recognized as a critical factor in improving teachers' effectiveness in the classroom and in increasing students' academic performance; and a role for universities in providing professional growth for classroom teachers has emerged.

One respondent on the Texas Survey indicated a viewpoint about learning how to teach.
What you learn in school is just a beginning. Lifelong learning about science is needed for effective teaching.[1]

Early models of professional development in science often focused either on strengthening the classroom teacher's content knowledge or on strengthening content knowledge and pedagogy separately. Traditional teacher enhancement experiences occurred in summer workshops, often

offered on university campuses by experts in the fields of science and/or in pedagogy. Content and pedagogy were seldom offered together and usually without input from classroom teachers. Classroom implementation occurred during the school year after the university-based experiences were complete; and the actual translation of the new content was left up to the teacher. Teachers connected their university summer learning experiences and the real world of their public school classrooms without feedback, mentoring, or supervision. This method of incorporating professional development experiences into classroom practice is a far cry from new recommendations regarding professional development.

> The development of pedagogical content knowledge by teachers mirrors what we know about learning by students; it can be fully developed only through continuous experience. But experience is not sufficient. Teachers also must have opportunities to engage in analysis of the individual components of pedagogical content knowledge—science, learning, and pedagogy—and make connections between them.[2]

In conventional models of professional development in science, classroom teachers received instruction from university specialists who were generally uninformed about the unique challenges, stresses, and barriers of elementary teachers. University teachers of science were often unfamiliar with the elementary classroom learning environment. Although very familiar with latest developments in scientific knowledge, university specialists were able to offer only limited assistance to classroom teachers struggling to make new connections between the science they were learning and the realities of elementary classrooms. Some externally funded programs may have required two or three follow-up classroom visits for evaluation purposes, but there were few other opportunities for university instructors to engage in mentoring experiences that would have benefitted both teachers. University instructors rarely saw the ultimate results of their summer workshop efforts. In conventional models for professional development, enhancement was directed towards the elementary teacher's science content knowledge and not towards her incorporation of the new knowledge into the classroom environment. Furthermore, these models did little to provide feedback to the university specialists that might have strengthened his or her effectiveness in teaching.

The *National Science Education Standards* promote the development of new visions for science education where there are no traditional distinctions between "targets," "sources," and "supporters" of teacher development activities; where there has been a shift from the conventional view of professional development for teachers from "technical training skills" to "opportunities for intellectual professional growth;" and where practicing teachers—traditionally the target for professional development—are recognized as a source essential for their own growth as well as a valuable resource in supporting the growth of other teachers of science. [3]

The current reform effort in science education calls for a substantive change in how science is taught and equally substantive change in professional development at all levels.[4]

Professional development is no longer perceived as a "catch-all" for collections of isolated experiences designed to "fix" classroom teachers. In science, professional development begins with undergraduate education and continues seamlessly throughout the teaching careers of all teachers of science. New professional development models aim to enhance the effectiveness of all teachers of science, not just classroom teachers. University instructors, classroom teachers, preservice teachers, and science learners of all ages are welcomed members of "learning communities." All members are co-learners, performing roles as teachers and learners simultaneously, learning from each other as to how to best enhance their own science teaching. Teachers of science from public schools, colleges, and universities learn how to support and learn from one another.

In learning communities that focus specifically on teacher preparation, all teachers of science strive to simultaneously enhance their teaching effectiveness in their roles as preparers of prospective elementary teachers. Classroom teachers offer their expertise as specialists in public school teaching. They join forces with university instructors of content and pedagogy in order to construct collaborative models that benefit all members of the community, as well as prospective teachers. Each member has perspectives and challenges that are unique to the learning environment in which they teach. Preservice teachers, interns, experienced teachers, and university specialists pool their resources and share their perspectives to face the challenges confronting them. They increase their understanding of standards and benchmarks available to them by national, regional, and state groups; they seek avenues for acquiring and maintaining state-of-the-art instructional materials, laboratories, and centers; and they learn to rely on themselves and on each other to improve their abilities to use action research, reflection, peer review, mentoring, and other professional growth experiences. As much as possible, the professional development of teachers and preparation of prospective teachers occurs in the context of the public schools, where "learning to teach science ... take[s] place through interactions with practitioners in places where students are learning science."[5]

- **All teachers of science participate in school-based experiences that provide relevant contexts for increasing their effectiveness as science teachers.**

Collaborative models require shared goals, knowledge, skills, and experiences among those responsible for preparing teachers. Shared vision occurs when all partners in science have common experiences that are directly related to science teaching in the public schools. Robert Yager and his associates describe the design and implementation of relevant and meaningful science.

> A partnership does not mean having science faculty on one side, defining a discipline-based major, while education stays on the other side, defining a program to meet licensure in a given state. The scientists should become full partners in the preparatory program. [6]

Leadership in responsible science teaching needs to be redefined in terms of commitment to the needs of children and to the needs of teachers who are teaching science to them. [7]

The commitment for *college and university instructors* includes stepping out of the zone of comfort afforded by the academy and stepping into the classrooms of public school elementary teachers who are teaching science. How else can one understand the unique perspective of the elementary teacher who is teaching science? How else can one compare his or her own pedagogical content knowledge in science with that of the classroom teacher? All skilled teachers of science have special understandings and abilities that integrate their knowledge of science content, curriculum, learning, teaching, and students,"[8] but the pedagogical content knowledge required to be effective in the university classroom of preservice teachers is different than that required to be effective in a classroom of science majors or even non-science majors who are not preparing to teach science. Effective university teachers of science understand that the acquisition of science knowledge is only one strand in the complex tapestry of knowledge woven by effective teachers of science, and they use that understanding to provide learning experiences that are meaningful to their students. Teachers of science who are effective with prospective elementary school teachers understand the complex requirements necessary for elementary school science teaching. They recognize that prospective elementary teachers are unique learners of science who perform dual learning roles: they are not only learners of science; they are also learners of science teaching. Educators of preservice teachers incorporate that understanding into their own construction of pedagogical content knowledge to make their own connections between their students, the science content they are teaching, and the pedagogy that they are modeling.

The commitment of *induction-year teachers* involves setting personal goals that include science as a high priority in their classroom teaching. Induction-year teachers begin to use science as a context to interest and motivate children's learning in other content areas such as mathematics, reading, and social studies. They also continue their professional development in the public school arena, joining networks of other teachers of science to continue to improve their knowledge and skills in teaching science. The realities of the first years in the classroom require new teachers to learn how to work within the complex system of the public school: how to work with other teachers, take advantage of professional development opportunities, and learn by reflective practice from their own experiences and the experiences of others. [9]

The commitment of *experienced elementary teachers* includes mentoring new teachers

as they begin their teaching careers, as well as providing encouragement and guidance to preservice teachers who may be engaged in a variety of different types of field experiences within the school setting. Experienced elementary teachers become active partners in the establishment, maintenance, and evaluation of learning communities developed to strengthen the science preparation of prospective elementary teachers. They provide their expertise in numerous ways, confident in the value of their knowledge and experiences in elementary science teaching.

Learning communities comprised of university, public school, and prospective teachers of science understand that *preservice teachers' commitment* to science teaching grows with positive school-based experiences that begin in the earliest years of their professional teacher preparation. The learning community recognizes that student teaching experiences in isolation are not sufficient to produce good elementary science teachers. Learning communities encourage and supervise the development of innovative courses and experiences that prepare elementary teachers to learn and teach science in a variety of learning environments and teaching situations. For instance, science content instructors may provide special laboratory sections for future teachers in which consideration is given to how best to teach the material being covered; [10] or they may provide special opportunities for prospective teachers to teach science content as they are learning it. Learning science and learning how to teach science may occur in the context of a science content course, a methods course, or a special course that combines both content and methods. Whenever possible, however, the content for learning to teach science involves actual students, real student work, and outstanding curriculum materials.[11] Learning communities committed to elementary school science teaching provide positive experiences that start early in the preservice program and thus set the stage for a lifetime of positive science teaching experiences.

What do college students think of realistic teaching experiences? Student teachers value the learning opportunity.

The best way to learn is by...doing it, making mistakes and learning from mistakes.

The experience—that's the most useful thing I can get from student teaching. Experience—it's fine to read about it in a textbook, but to actually do it is totally different.[12]

A nationally recognized kindergarten teacher made the following comments about early science teaching experiences and student teaching.

They need to get out in schools more. If you have identified some redally good science teachers, have the preservice teachers assist with labs. It's too late by the time you get to student teaching. Get rid of observations and have them do internships. Universities should couple programs with schools to get preservice teachers in the field.[13]

Finally, learning communities committed to the science preparation of elementary teachers provide learning experiences in a variety of school settings to enhance their abilities to effectively adapt instruction to meet the diverse needs of the children in their classrooms. Very early experiences that provide first-hand knowledge about similarities and differences in elementary school children can be invaluable. Intervening variables that may affect children's learning in science include socioeconomic status, gender, learning abilities and styles, cultural heritage, language, beliefs, work habits, needs, interests, unique endowments, personality, and physical abilities. Today's elementary teachers are successful when they design student-centered learning experiences that reflect the diversity of their students and when they show consideration and respect for the unique characteristics of all children in their classrooms.[14] Texas author Rosa Guerrero wrote the following:

> We are the threads that are woven into a multicultural tapestry, the fabric of American life. We are like notes in a chord of music ... If all the notes were the same, there would be no harmony, no real beauty ... because harmony is based on differences, not similarities.[15]

Teaching science that is meaningful to all elementary children depends on much more than the possession of science knowledge, more than the utilization of various instructional models, more than knowledge of scientific methods of study, and more than the capability to do research. Teaching science that is relevant to elementary children depends on a rich variety of experiences by all teachers of science who are committed to the process of educating children: science content instructors, science methods instructors, experienced and induction-year teachers, and preservice teachers.

Perhaps the greatest and least understood need in the new models of teacher preparation and professional growth is the expanded role of college and university instructors of science. Science education reform calls for college and university faculty members who possess the knowledge and skills to directly influence the science teaching of elementary teachers and the science learning of elementary school children. Traditional models of teacher preparation involved college and university faculty in familiar and comfortable roles associated with teaching undergraduate science classes. Traditional models of professional development involved college and university faculty with limited exposure to public schools and classrooms. New models require the reconstruction of these roles to ones that are unfamiliar to many teachers of science from colleges and universities. These new roles, unfortunately, may be met with resistance by university colleges, departments, and teachers of science. Many changes must occur with the adoption of contemporary models that simultaneously incorporate preservice preparation and professional development experiences. Significant changes must be made in reward structures to encourage active participation of university faculty in teacher preparation,[16] and new ways to

foster interactions among faculty in the science disciplines with those in schools of education must be implemented.[17] Even so, it is with the spirit of equally shared responsibility and reward among all teachers of science, including college and university faculty, that the following indicators are recommended.

- **All teachers of science use content standards to guide their decisions about effective science teaching practices.**

Rodger Bybee establishes the thesis for *Reforming Science Education: Social Perspectives and Personal Reflections.* His analysis of historical trends since the turn of the century (1880-1920) reveals recognizable stages of transformation in science education that are distinctly correlated with specific types of social change.

> All the evidence indicates that science education will change owing to the new societal demands; some will seek to reform the old, while others will seek to build anew. Whichever is the case, the consequences of not changing are too severe to abdicate our responsibility to facilitate a new transformation of science education.[18]

For over a decade, reform of science education has been on the national agenda. A significant difference in this tide of reform has been the setting of national goals and development of national standards to "bring coordination, consistency, and coherence to the improvement of science education"[19] at local levels. Support for national education standards by state governments originated in 1989, when the National Governors Association endorsed national education goals.[20] Even before 1989, however, the American Association for the Advancement of Science (AAAS) challenged science educators to create a new vision of science education for all American citizens. *Science for All Americans*[21] was written as the position statement of Project 2061, a new group of practicing science education formed by the AAAS to lead their national reform initiative in science education. Since that time, science literacy for all high school graduates has emerged as one of the national goals of K-12 science education. With this focus, new questions have emerged at both national and state levels regarding what science students should know and be able to do in order to be scientifically literate. At the local level, questions continue to be asked about what "best practices" will achieve this goal.

Three documents, similar in their focus but different in form and purpose, have elaborated ideas that were first articulated in *Science for All Americans*, focusing on the knowledge and skills that literate citizens will need in order to live, learn, and work in a rapidly changing world driven by technological advancement. The *Benchmarks for Science Literacy* and the *National Science Education Standards* have strongly influenced the development of state and local curriculum frameworks across the nation.[22] In our own state of Texas, both documents have played essential roles for the writing teams for our own state standards, the *Texas Essential*

Knowledge and Skills in Science (TEKS).[23] *Benchmarks* and *National Standards* were used as resources to create the *TEKS*, a coherent document that reflects the perspectives of Texas science educators within the larger context of national reform.

The creation of documents, however, has not solved problems for teachers of science and their learning communities who have been pressed to address science reform in their local programs. The creation of these documents has instead stimulated more questions. How are the two national documents and our own Texas standards—the *Benchmarks*, *National Standards*, and *TEKS*—best used by teachers of science in this climate of reform? What are the contents of each of these documents? How are the documents alike and how are they different? Of what real value are these documents to teachers of science who are committed to strengthening the science preparation and professional development experiences of prospective and practicing teachers? What role can these documents play in the design of continuous growth experiences for teachers of science?

The discussion that follows answers several questions regarding the utility of these documents within the context of three recommendations regarding their use in science education reform. Three uses of these documents are suggested below in guiding teachers of science through growth experiences related to reform in science education. These uses include Forging a Vision, Judging Quality, and Designing Curriculum Frameworks.

Forging a Vision. Used together, these three documents can begin the dialogue among communities of science educators who are in the early stages of forming a common vision of the science education program they will either restructure or build to serve *all* of their students. Peter Senge writes, "If any one idea about leadership has inspired organizations for thousands of years, it's the capacity to hold a shared picture of the future we seek to create."[24] Genuine visions bind people together around a common identity and sense of destiny. Study and discussion of these documents can focus learning communities on issues surrounding the establishment of their new goals of reform in science education. Members who have had a role in constructing shared visions can become inspired to seek new and better answers to the pervasive questions of how best to strengthen the science education of elementary children and their teachers.

All three documents reflect the common visions of the teams of professional science educators who wrote them. (It is significant to note that all teams represented members of the science education community from the private sector, public schools, and universities and colleges.) The *Benchmarks* are a collection of statements about science content goals, written in common language and "shared within the vision of science literacy," statements of the "lasting knowledge and skills we want students to acquire by the time they are adults."[25] As such, they provide ample ideas for dialogue and discussion of issues. The *National Standards* complement the *Benchmarks* by considering more than content concerns. They "provide frames of reference

for judging the quality of teaching, professional development, assessment, science education programs, and educational systems."[26] The *TEKS* are standards for grades K-12 that have been mandated by Texas state law, and *TEKS* provide a vertical structure for connecting knowledge and skills that build scientific understandings from one grade level to the next, as well as a horizontal structure of integrated knowledge and skills that are developmentally appropriate for each grade level.

The *Benchmarks, National Standards*, and *TEKS* were written by science educators who forged their own collective visions. All three groups adopted a key concept in contemporary science teaching and learning: "less is more." This statement summarizes the belief of these reformers that a selected subset of essential science concepts, generalizations, and skills provides deeper science understandings and skills than an "overstuffed curriculum that places a premium on the ability to commit terms, algorithms, and generalizations to short-term memory and impedes the acquisition of understanding."[27] In other words, the writers of these documents believe that students must

> see the big picture and work with important constructs, models, and theories to develop both critical reasoning skills and deeper understandings of the processes as well as the essential content of science.[28]

"L ss is more" is a key concept that should not be overlooked by teachers of science who take on the task of forging their own collective visions for the development of programs that better serve all students. Food for thought, this concept may stimulate provoking discussions centering on the changes that must occur in conventional teaching and assesment practices.

Judging Quality. These documents may be used as references for judging quality in local curriculum choices. *Benchmarks* specify levels of understanding and ability by the end of grades 2, 5, 8, and 12, suggesting "reasonable checkpoints for estimating student progress toward the science literacy goals outlined in *Science for All Americans*."[29] The *Benchmarks* were written as a tool to be used by educators in designing curricula that meet the goals of science literacy for all students, relying heavily on research associated with students' learning and understanding about science. A chapter entitled "The Research Base" surveys the research literature relevant to the selection and grade placement of the *Benchmarks*. The *Benchmarks* also provide scientific explanations that were intentionally written to avoid technical language so that they can be more easily interpreted by teachers who may need to know more about the science concepts that they are expected to teach. (In that regard, the *Benchmarks* can be very useful to elementary teachers for background information about science.) Other suggested uses have been provided by the *National Standards and Bencharmarks in Science Education: A Primer* (an ERIC Digest) as follows:

Benchmarks can be used by:

- Teacher groups, administrators, school-board members, parents, interested citizens, and scientists to relate science literacy to the school setting.
- Committees of teachers and specialists to measure the curriculum and make improvements.
- Developers of curriculum to create materials.
- Test writers to develop appropriate materials and assessment techniques.
- Institutions of higher learning to prepare teachers.
- Researchers to pinpoint areas where further studies are needed.[30]

The *National Standards* remind us that the term "standard" has multiple meanings, but that

> Science education standards are criteria to judge quality: the quality of what students know and are able to do; the quality of the science programs that provide the opportunity for students to learn science; the quality of science teaching; the quality of the system that supports science teachers and programs; and the quality of assessment practices and policies. Science education standards provide criteria to judge progress towards a national vision of learning and teaching science in a system that promotes excellence, providing a banner around which reformers can rally.[31]

Therefore, the *National Standards* elaborate standards of quality for science teaching, for professional development, for teachers of science, assessment in science education, science education programs, and science education systems. There are, of course, content standards as well. The document suggests that different people will read the *National Standards* in different ways.

> Teachers, for example, might want to read the teaching, content, and program standards before turning to the professional development, assessment, and system standards. Policy makers might want to read the system and program standards first, while faculty of higher education might want to read the professional development and teaching standards first, before turning to the remaining standards.[32]

The *Texas Essential Knowledgve and Skills (TEKS)* are building blocks for designing effective science programs in local schools and districts that include learning experiences for all Texas students to achieve understanding and ability in all *TEKS* in every grade level. Teachers of science can use the *TEKS* to compare and contrast the content objectives that they are currently teaching with those required by the state. Curriculum audits using the *TEKS* can simultaneously show deficiencies and recommend corrections at each grade level. In teacher preparation programs, the *TEKS* can guide the choice of learning experiences for prospective teachers that

will satisfy these new standards of science content that elementary teachers will be expected to know and be able to teach in science.

Designing Local Curriculum Frameworks. Learning goals for children in grades K-8 in the *Texas Essential Knowledge and Skills (TEKS)* are not separated into the traditional categories of life science, physical science, and earth science. The *TEKS* in these grades present science content learning goals from all science disciplines at each grade level. (Learning goals organized along more traditional lines are established in grades 9-12). The structure and organization of the curriculum framework that organizes the learning goals for grades K-8 have been left to individuals at local levels to design, implement, and evaluate.

Effective science programs rely on curriculum frameworks that are coherent, cohesive, and logical. The *National Standards* remind us that "curriculum is the way content is delivered; it includes the structure, organization, balance, and presentation of the content in the classroom."[33] Curriculum frameworks organize the scope, sequence, and coordination of concepts, processes, and topics into manageable units of instruction. There are many ways to build curriculum frameworks.

> Curricula will often integrate topics from different subject-matter areas—such as life and physical sciences—from different content standards—such as life sciences and science in personal and social perspectives—and from different school subjects—such as science and mathematics, science and language arts, or science and history.[34]

Conventional methods for organizing content may not be the most effective way to build a curriculum framework that serves the science literacy needs of all science learners. Information from the organization of content standards within the *Benchmarks* and *National Standards* can assist local teachers of science in looking at science content in nontraditional ways. The *Benchmarks*, for example, provide learning goals organized around categories that include titles such as "The Nature of Science," "The Physical Setting," "The Living Environment," "The Designed World," and "Common Themes." The *National Standards* include both nonconventional and conventional categories of content standards. "Science in Personal and Social Perspectives," "Unifying Concepts and Processes," and "Science as Inquiry," for example, are included among traditional categories of "Physical Science," "Life Science," and "Earth and Space Science."

Comparing, contrasting, and correlating the *Texas Essential Knowledge and Skills (TEKS)* with corresponding *Benchmarks* and *National Standards* will assist and inform science learning communities as they develop deeper understandings about how to implement learning goals through the design of their curriculum framework. A suggested process for building such frameworks is elaborated in the "Standards for Science Education Programs" (Chapter 7 in the

National Standards), which can be used to provide direction to individuals and groups responsible for designing, implementing, and evaluating curriculum frameworks that lead to a thoughtfully designed and implemented science program that provides comprehensive and coordinated experiences for all students.

In summary, these three documents can form the core of the new knowledge and skills that Texas teachers of science must possess in order to create and deliver programs that serve the needs of the learners for whom they are responsible. Continuous growth for all teachers of science involves their construction of both breadth and depth in new knowledge about reform and the roles that they can play in the process. *Standards*, and documents like them, can be used as catalysts to initiate the processes of growth for teachers of science who wish to be effective, as well as informed, in this age of science education reform. *Standards* were designed to inform and guide committed science educators in their journeys toward improved programs. *Benchmarks, National Standards*, and *Texas Essential Knowledge and Skills (TEKS)* can be used as resources in the establishment of goals and expectations for student achievement; in the selection and organization of science content into curriculum frameworks; and in the acquisition of knowledge about new teaching and assessment strategies.

Effective science programs that prepare teachers and provide professional development experiences use guidelines, benchmarks, and standards wisely to establish goals aligned with statements of philosophy, the vision that drives the program, and the statements of purpose that the program is designed to achieve. All teachers of science should understand and be able to use these documents to assist them in their individual and collective journeys towards the development of new programs that enhance the scientific literacy of their learners.

- **All teachers of science use state-of-the-art materials and equipment, including computer technology and well-equipped instructional laboratories and centers, to support student inquiry.**

The *National Science Education Standards* challenge all teachers of science to support student inquiry in their science classrooms. Student inquiry experiences provide the basis for observation, data collection, reflection, and analysis of natural phenomena. In their early years of school, children can investigate earth materials, organisms, and properties of common objects. They develop concepts and vocabulary from these experiences, but they also can develop inquiry skills.[35] The *Standards* suggest that students use a variety of materials and equipment, including rulers, thermometers, watches, beam balances, spring scales, magnifiers, microscopes, calculators, and computers. Secondary sources that include media, books, and journals in a library also support student inquiry.[36]

> In successful science classrooms, teachers and students collaborate [on] the pursuit of ideas, and students quite often initiate new activities related to an

> inquiry. Students formulate questions and devise ways to answer them, they collect data and decide how to represent it; they organize data to generate knowledge; and they test the reliability of the knowledge they have generated. ... At all stages of inquiry, teachers guide, focus, challenge, and encourage student learning.[37]

In early years, students develop simple skills to support their inquiries about objects, organisms, and events in the environment. Simple manipulative skills, such as cutting, switching, pouring, and measuring, involve the development of abilities to choose and use instruments such as rulers, balances, magnifying glasses, and scissors. They also develop their skills in choosing media and resource books to support their individual inquiries, and in the use of computers and calculators for conducting investigations. As student inquiries become more complex and open ended, a diversity in tools is essential to support their investigations. An effective science learning environment requires a broad range of basic scientific materials, as well as specific tools for particular topics and learning experiences.[38]

One exemplary first grade teacher had some ideas about hands-on science teaching.

> *Sometimes it is hard to set up things for science because it involves materials and stuff. You have to work harder teaching science; but it is so much better than keeping kids in their chairs working on things they could care less about.*[39]

Science literacy requires an understanding of science and its place in modern society. Science literate students understand the central role of inquiry in the scientific enterprise. They understand that scientists' roles in society are based on their abilities to pose questions and actively seek answers using appropriate resources. Just as scientists use technology to answer their research questions, children in the classroom also can use technology to answer their own research questions, collect their own data, and make conclusions on the basis of the data they have collected. Computers and computer technology have revolutionized the scientific enterprise, just as they are revolutionizing public school classrooms. Elementary teachers who use current technologies in their instruction are capable of modeling information-seeking and information-finding with their students. Tools from the information, communication, and computing technologies can be integrated seamlessly into the educational process. Use of these tools can become a part of the "dailiness" of the elementary science classroom. Of current interest is the World Wide Web, which has become synonymous for some computer users with the Internet. On the Web, students can inquire into areas that interest them, view the work of other students, produce knowledge, interact with others, and have access to information and ideas that have never been available to students before.[40]

With the integration of new technologies, traditional reliance on teacher-directed formats of lecture and verification or "cookbook" laboratory experiences becomes increasingly anachronistic.[41] New models of computer-assisted inquiries require new models of instruction, where teachers must give up the old yardstick measure of succesful science teaching.

> At some point, questions of what is taught must give way to considerations of why something is being taught. With the explosion of knowledge in all disciplines, equating quality with the coverage of as much material as possible is fundamentally misguided. Students need the intellectual tools to explore new areas and topics thoughout their lives so that they can respond to change rather than trying to anticipate it by increasing the bulk of acquired "knowledge."[42]

Well-designed, active learning environments assist in the development of skills and traits that extend much farther than the elementary classroom. The essence of resources that support inquiry, including new computer technologies, is the empowerment of the user. Inevitably, the focus on inquiry-based instruction leads to learning that is both active and under the control of the learner. Learners who are actively engaged in the learning process and using multimedia and information technology tools almost inevitably work together in groups or teams, sharing insights and experiences. In the process, they learn teamwork, communication, and organizational skills, as well as science content matter.[43]

The lack of specific knowledge about educational hardware and technology has been noted as a barrier to strengthening the science experiences of all learners of science, from elementary school children to undergraduates. Effective teachers of science have the knowledge and skills to provide technological support for inquiry-based instruction in their classrooms. Their students understand the nature of science and the role of scientific inquiry in the quest for new knowledge, for learners and scientists alike. New teachers are expected to use and select the most appropriate science materials and to make decisions about when, where, and how to make them accessible. Experiences of science undergraduates that model the form and function of scientific inquiry can provide the foundation for continued growth, and the appreciation for and understanding of varied resources in inquiry teaching and learning.

- **All teachers of science seek to improve their science teaching through collegial relationships that encourage reflective practice and shared educational opportunities.**

Effective teachers of science seek opportunities to continue learning about science and the teaching of science. "Becoming an effective science teacher is a continuous process that stretches from preservice experiences in undergraduate years to the end of a professional career."[44] Many sources indicate that ongoing learning about science and science teaching is facilitated by involvement with others.

One presidential awardee had some suggestions regarding collaborative professional development.

Formal networks between teachers and others should be established. There should be opportunities for science teachers to interact during the achool year and uplink information with strategic people.[46]

The challenge of professional development for teachers of science is to create optimal collaborative learning situations in which the best sources of expertise are linked with the experiences and current needs of teachers.[45]

As with any professional practice, teaching should be viewed as a life-long process of reflection, education, and peer support. Increases and changes in knowledge about pedagogy, scientific content, and technology form the core of meaningful professional development experiences for all teachers of science. Opportunities for the enhancement of practice include seminars, institutes, curriculum development groups, study groups, mentoring partnerships, and committed reflective practice.

Successful mentoring partnerships benefit all parties. Mentors provide expertise from their unique perspectives. Excellent professional development programs restructure the roles of the four teachers of science to benefit all parties: preservice teachers, practicing teachers, professors of science content, and professors of education. The *National Science Education Standards* recommend that programs

- Provide opportunities for teachers to learn and use various tools and techniques for self-reflection and collegial reflections, such as peer coaching portfolios, and journals; and

- Support the sharing of teacher expertise by using mentors, teacher advisors, coaches, lead teachers, and resource teachers to provide professional development opportunities.[47]

Appropriate implementations of science content knowledge in the elementary classroom can be monitored and assessed by professors of science and education, experienced classroom teachers, and preservice teachers themselves. Debriefing field-based science teaching experiences becomes "an appropriate way to learn how to teach science,"[48] as well as an excellent way to familiarize college and university faculty members with science teaching in the elementary school.

> Frequent discussions with student teachers before, during, and after their student teaching are necessary to help them ascertain what can be or has been learned from their experiences ... Experience also is not enough. It is the thought and subsequent action associated with the experience which determines its value in the learning process.[49]

One fifth grade presidential awardee explained the value of attending the state science teachers' conference.

I started going to CAST and meeting other teachers ... and others from universities and they gave me courage to do things differently in my classroom.[51]

Presidential awardees made frequent references to various opportunities for professional development in scientific knowledge. One awardee considers how one intense summer interaction with other teachers gave her the courage to change her teaching.

We [a group of 26 teachers] spent six weeks together in the summer. ...We traveled together exploring and learning. Everyone shared what they were doing in the classroom. On this trip I realized that teachers in other places are doing things differently and so could I. This is when I started doing things differently.[52]

One teacher spoke of the value of continued classes.

Graduate level courses were more stimulating because I was there with teachers and professionals in education.[53]

Another teacher indicated the personal value of reading.

I read professional magazines, newspapers, scientific stuff [like] Science News. Now with Internet and computers, we have America On-Line at home and it is used in the schools [as well].[54]

The roles of all teachers of science are varied in new models of professional growth experiences, and parterships need to be two-way exchanges.[50] College and university teachers of science might mentor new science teachers, supervise student teachers, serve on advisory boards, and form partnerships with excellent practicing science teachers to develop, implement, and assess preservice and inservice programs. Experienced public school teachers could engage in collaborative partnerships and perform mentoring functions for university faculty as well as less experienced teachers, with a major role in supporting preservice teachers in school-based settings. Intern teachers engage in team teaching, visiting other science teachers' classrooms, and establishing informal and formal networks within the school environment to increase their proficiency in teaching science. Preservice teachers should be encouraged to appreciate the opportunity to reflect on the multiplicity of experiences and perspectives provided by the collaborating partners across the science education community.

Knowledge about current pedagogy is only effective if it is orchestrated within the context of teaching current, accurate scientific knowledge. Teachers who continuously grow in their scientific knowledge attend science institutes, conferences and workshops, converse with other teachers, and read scientific journals.

Teaching for the technological and scientific century ahead means to be prepared

to convey scientific knowledge and technological skills. Effective elementary teachers create learning environments in which students develop fundamental understandings about life, earth, and physical sciences. New educational technologies reflect changes in emphasis away from science as *fact* and towards science as a *life skill.* Effective elementary teachers seek to stay current with the changing nature of scientific knowledge and the appropriate manner in which it should be delivered.

Andrea Foster's synthesis of the interviews of the six presidential awardees in elementary science teaching[55] revealed a pattern in their references to their professional development experiences. Their significant professional development experiences were typically described as "intensive, long term, relevant to the teaching of science content, and in many cases out in the field."[56] One teacher remarked that

> You have to have the idea that you don't know it all — that you are a constant learner ... and, that science is probably one of the fastest changing fields. You have to be a constant learner in science. There is still so much I need to organize and know and I still have a long way to go even with twenty five years [of teaching experience]. [57]

These accounts from exemplary teachers regarding the effects of intense science experiences, often offered as summer science field trips, provide food for thought in regard to the teaching and learning of science. Perhaps all teachers of science should focus on the value of experiences that provide prolonged engagement for science learners to "do science as scientists do." One exemplary teacher said that "the more knowledge [she had], the more secure [she felt] in asking questions and turning them loose to do research for themselves."[58] Implications for teaching science to inservice teachers include the possiblity of offering science learning experiences during the summer when intense, prolonged engagements are possible. Implications for teaching preservice teachers are similar, with experiences offered as undergraduate science courses perhaps offered simultaneously with inservice teachers to enhance preservice teachers' learning to teach science while learning science by doing science. Implications for all teachers of science are that prolonged student inquiries conducted in the field by teachers have positive effects on science learners. Outcomes include increased knowledge of the nature of science as well as increased knowledge of science content and increased confidence in teachers' beliefs about their abilities to teach science.

Conclusion

Professional growth occurs from collegial learning experiences that benefit all participants. Learners of all ages are social by their nature and benefit from interactions with each other. Teachers involved in meaningful professional development experiences learn as

much from each other as they do from the experience itself. Effective professional development experiences build on shared interests in teaching improvement and take advantage of the experience and knowledge of all participants. All involved in the experience offer their own unique perspectives, particular strengths, and specific needs for improved teaching. Changes and improvement in teachers' knowledge of content, pedagogy, and technology are maximized in learning environments where the vision and goals of the experience are shared by all participants. Early identification of common goals and individual needs provide a collegial context for all to learn and grow in an atmosphere of trust and shared ownership of the professional growth experience. Improved teaching occurs with careful mentoring and peer review. Reflective practice forms the core of improved teaching. When teachers have the time and opportunity to reflect on their own views, to evaluate their learning and teaching, to conduct inquiries on their own teaching, and to compare, contrast, and revise those views, they come to understand the nature of exemplary science teaching. Teachers are reflective and evaluative when they demonstrate critical thinking and problem solving, display open-mindedness, and accept responsibility for decisions they have made. Enhanced reflection occurs with feedback from another's observations and viewpoints on the process and products of the reflection. Shared, continuous, and prolonged growth experiences promote collegiality and enhanced teaching. New models of professional development employ the strengths and perspectives of others to enhance the teaching effectiveness of all teachers of science, including preservice teachers just beginning to understand the unique challenges of elementary science teaching.

Questions to Consider

1. Is it possible for teachers of science to upgrade their knowledge and skills in science as they are also upgrading their science teaching skills?
2. How can the design of life-long learning programs impact the design of teacher education programs?
3. How should professional development experiences be structured to optimize learning for all teachers of science? How do teachers of science best learn from each other?
4. What strategies are effective in cultivating a true concern for public education in institutions of higher education?

Endnotes

[1]Dawn Parker, "Preservice Elementary Science: A Description of Programs at Colleges and Universities in Texas," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996) 30.

[2]National Research Council, *National Science Education Standards* (Washington: National Academic Press, 1996) 63.

[3]*National Science Education Standards* 57-58.

[4]*National Science Education Standards* 56.

[5]*National Science Education Standards* 58.

[6]Robert Yager, Martha V. Lutz, and John A. Craven III, "Do National Standards Indicate the Need for Reform in Science Teacher Education?" *Journal of Science Teacher Education* 7.2 (1996): 88.

[7]Yager.

[8]*National Science Education Standards* 62.

[9]*National Science Education Standards* 57.

[10]Gloria Appelt Slick, *The Field Experience: Creating Successful Programs for New Teachers* (Thousand Oaks: Corwin Press, 1995) xxiv.

[11]*National Science Education Standards* 67.

[12]Sue Johnston, "Experience Is the Best Teacher, Or Is It? An Analysis of the Role of Experience in Learning to Teach," *Journal of Teacher Education* 45 (1994): 203.

[13]Andrea Foster, "Interviews of Elementary Science Presidential Awardees: Patterns That Portray Excellence in Science Teaching," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996) 15.

[14]Texas Education Agency, *Learner-Centered Schools for Texas: A Vision of Texas Educators* (Austin: TEA, 1995) 6.

[15]Gloria Appelt Slick and Kenneth Burrett, *Emerging Trends in Teacher Preparation: The Future of Field Experiences* (Thousand Oaks: Corwin Press, 1995) 20.

[16]William E. Kirwan, "Keynote Address: Role of Faculty in the Disciplines in Undergraduate Education of Future Teachers," *Proceedings of the National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers* (Washington: NSF, Aug. 1993) 20.

[17]National Research Council, *From Analysis to Action: Report of a Convocation* (Washington, National Academy Press, 1996) 17.

[18]Rodger W. Bybee, *Reforming Science Education: Social Perspectives and Personal Reflections* (New York: Teachers College Press, 1993) 19.

[19]*National Science Education Standards* 12.

[20]*National Science Education Standards* 13.

[21]American Association for the Advancement of Science, *Science For All Americans* (Washington: AAAS, 1989).

[22]D. Close, J. Miller, L. Titterington, D. Westwood, "National Standards and Benchmarks in Science Education: A Primer," *ERIC Clearinghouse for Science, Mathematics, and Environmental Education Digest* (Sept. 1996) 2.

[23]Texas Education Agency, *Texas Essential Knowledge and Skills in Science* (Austin: TEA, Sept. 1997).

[24]Peter Senge, *The Fifth Discipline* (New York: Doubleday, 1990) 9.

[25]American Association for the Advancement of Science, *Benchmarks for Science Literacy* (New York: Oxford UP, 1993) xi.

[26]*ERIC Digest* 1.

[27]*Benchmarks* xi,xii.

[28]*ERIC Digest* 2.

[29]*Benchmarks* xi.

[30]*ERIC Digest* 2.

[31]*National Science Education Standards* 12.

[32]*National Science Education Standards* 3-4.

[33]*National Science Education Standards* 22.

[34]*National Science Education Standards* 23.

[35]*National Science Education Standards* 121.

[36]*National Science Education Standards* 33.

[37]*National Science Education Standards* 33.

[38]*National Science Education Standards* 44.

[39]Foster 8.

[40]Jon Margerum-Leys, "Making Sense of the World Wide Web," Presentation at the Annual Meeting, School Science and Mathematics Association, Milwaukee, Nov. 1997.

[41]National Science Foundation, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology* (Washington: NSF, 1996) 21.

[42]*From Analysis to Action* 22.

[43]*Shaping the Future* 21.

[44]*National Science Education Standards* 55.

[45]*National Science Education Standards* 58.

[46]Foster 6.

[47]*National Science Education Standards* 68.

[48]Kenneth G. Tobin, "Learning How to Teach Science," *Effective Interaction of Science Teachers, Researchers, and Teacher Educators, Monograph 1*, Southern Association for the Educators of the Teachers of Science (1991) 8.

[49]Johnston 206-207.

[50]*From Analysis to Action* 16-17.

[51]Foster 9.

[52]Foster 8.

[53]Foster 8.

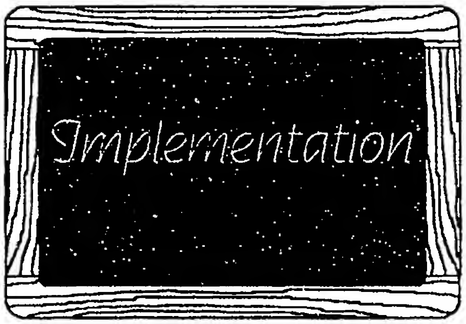
[54]Foster 9.

[55]Foster 50-52.

[56]Foster 51.

[57]Foster 52.

[58]Foster 46.



Directing Change

"I don't think I can have science yet. I'm not a good reader."..."I think you get science in Junior High. My brother is in Junior High and he has science."[1]

These are the voices of elementary children, voices that reflect the text-based reality of science teaching in elementary schools across the country. Many reform agendas, such as those expressed in these *Guidelines*, suggest that elementary science needs to focus more on inquiry and less on content, more on experience and less on rote memory. However, children and researchers alike continue to find that the textbook continues as "state of the art" methodology.[2]

Preservice elementary teachers, who come to college with limited science knowledge and confidence,[3] are legacies of their own underprepared elementary teachers.[4] Elementary teacher certification programs that have increased their numbers of science course requirements have not remedied the situation. Across the nation, most teachers do not feel well qualified to teach any kind of science, much less standards-based science.[5] New science literacy goals of "science for all" and "less is more" require teachers to possess a core of science knowledge as well as conceptual understandings about the nature of science and technology and the expanded roles of inquiry and investigation in elementary science programs.

Only recently has the science preparation of elementary teachers gained attention as an important piece in the puzzle of science education reform: a wide-angle view of school change that sees all aspects of the system as a whole. "If changes are to be long lasting, each and every component of the system must be irreversibly and permanently altered."[6] Systems thinking has replaced the notion that one course in science content or in science teaching methods, or even one innovative teacher enhancement program, will fix the state of science preparation for elementary teachers. No institution is capable of interrupting the historical traditions of the science preparation of elementary teachers. In fact, no one college—arts and science, education, or community college—can be held responsible. Nor can public schools year after year attempt to upgrade classroom teachers' science teaching skills in one-shot professional development workshops. Incredible challenges of numbers, attrition, and time constraints dilute the effects of even the best staff development programs in science.

Reform in science education has led to new visions of science teaching and learning as parts of a complex, interactive system. Changing the historic notion regarding the science

preparation of elementary teachers requires a shared, collaborative vision of all system stakeholders, including scientists, teacher educators, elementary teachers, and community leaders.

What about the realities of a state such as Texas? Texas elementary classroom teachers number 85,000 who teach in 3,715 schools across the state. Twenty Educational Service Centers (ESCs) are charged with the awesome responsibility of directing the continuing professional development experiences for these teachers. Reaching school teachers through a state-supported ESC system is a strategy with limited capabilities. Limitations are evident in the extreme differences in service needs between the large urban districts (Houston, Dallas-Fort Worth, and San Antonio ESCs serve two-third of the state) and the rural ESCs in west Texas where one ESC might serve 33 small school districts covering 37,500 square miles). Additionally, the state itself has not been particularly enlightened to science education reform. High-stakes, state-mandated tests tied directly to school district accountability systems have focused most staff development activities towards improving students' test scores in mathematics and reading. An elementary science test is not projected in the near future.[7]

Without high-level tests in place, how can science education reform in Texas compete with mathematics and reading initiatives? Funding from the National Science Foundation (NSF) for the Texas Statewide Systemic Initiative (Texas SSI) in 1994 gave science education the needed jump start. The overarching Texas SSI conviction is that "strategic coordination of policy development, site- and community-based capacity building, and educational infrastructure development—all focused on the implementation of a standards-based curriculum in every classroom for every child—will yield a system that is high performing and equitable."[8] Strategies for systemic change in Texas capitalize on the dispersed nature of local control and a centralized accountability system. These strategies follow three primary strands for implementing change: policy development (working from the top down); grass-roots, capacity building (working from the bottom up); and infrastructure development (convergence of human and financial resources through the middle."[9] This three-strand approach has placed the Texas SSI at the heart of *all* reform efforts in science education, from defining the statewide curriculum standards in science to strengthening the science preparation of elementary teachers. The Preservice Elementary Science Preparation (PESP) Action Team has operationalized the Texas SSI three-strand approach in its own work as follows.

Informing Policymakers (Working from the Top Down)

The composition of the PESP Action Team included individuals representing institutions most responsible for preparing elementary teachers: two- and four-year college and university faculty including both scientists and methods professors, public school curriculum specialists

and administrators, educational service center specialists, and master elementary school teachers. These leaders represented the geography and demographics of Texas, thus providing perspectives from rural and urban, as well as economically and culturally diverse, areas of the state. This group of science educators led the Texas SSI to envision bold new concepts for the science preparation of elementary teachers in the state.

These *Guidelines* are the product of the action team's first major task, to define the "ideal state" of science preparation for elementary teachers. The *Guidelines* were then used to compare the vision of the ideal state with the "real state" of current perspectives and practices in teacher preparation. Defining the real state was accomplished by designing and implementing three research projects that provided data from three perspectives: from institutions that prepare preservice teachers, from practicing teachers in the field, and from nationally recognized, "best of the best" elementary science teachers. Findings from these three studies included the following:

From Institutions That Prepare Teachers:

- *Elementary preparation programs* were generally traditional in delivery of science content and pedagogical practice;
- Collaborative partnerships at educational institutions in the state were limited;
- Most institutions designed and implemented programs within departments, only communicating and cooperating with other departments when necessary to handle state guidelines and requirements;
- Opportunities for early school-based science experiences were limited; and
- Needs ranged from awareness and information about reform to more complex needs of support and financial resources.[10]

From Award-Winning Elementary School Teachers:

- *Award-winning elementary science teachers* shared an innate curiosity and interest in the natural world that began in their early lives;
- They exhibited characteristics such as perseverance, drive, passion, and risk-taking;
- They felt unfulfilled by their own preservice preparation courses in science; and
- Their recommendations included the establishment of links between pedagogical instruction (how-to-teach) and science content instruction (what-to-teach), increased field experiences in science-rich settings, and stronger connections between elementary teachers and science content specialists.[11]

From Practicing Teachers:

- *Practicing elementary teachers* remembered very little about their preservice preparation;
- They identified the state-mandated mathematics and language arts tests as limiting factors in the time and effort they could spend in teaching science; and
- They requested information and knowledge about contemporary models of science instruction, including inquiry, more than materials or resources.[12]

Statistical data, scenarios, and teacher comments from these three research projects brought a real "state-of-the-state" focus to the *Guidelines* document, and many of the voices from these science educators that appear in the *Guidelines* were originally heard within the context of the research task of the PESP Action Team.

Building Grass Roots Capacity (Working From the Bottom Up)

Attempts to build grass roots capacity, as well as derive consensus of all science educated in teacher preparation, was another important thrust of the PESP Action Team's work. The *Guidelines* provided the focus of this effort, as well. Review drafts were presented and distributed to science educators at local, regional, and state meetings during the 1996-1997 academic year. Subsequent drafts incorporated changes suggested by important Texas stakeholders as a result of their valued feedback. In the late spring of 1997, the PESP Action Team also organized a conference to issue an incentive to develop innovative local models of preservice preparation that followed the suggestions provided in the *Guidelines*. Approximately 150 educators gathered to learn about the *Guidelines*, to build consensus regarding issues and concerns in preparing elementary teachers, to initiate meaningful collaboration, and to learn about opportunities for Texas SSI-funded planning and implementation grants. Conference participants attended the conference as collaborative teams of post-secondary faculty, museum directors, science supervisors, school administrators, and elementary teachers. Attendees left the conference with a Request for Proposals to fund summer planning grants and subsequent implementation grants for successful proposals. Of the thirteen collaboratives that received planning grant support, seven proposals were successful in receiving implementation grant funds. These proposals reflected the spirit and essence of each of the five guidelines and are currently (as of the spring of 1998) implementing their projects at their local sites.

Infrastructure Development (Convergence Through the Middle)

Implementation grants are currently bringing the vision home. Seven collaborative groups have received $30,000 each to implement specific projects to strengthen the science

preparation of the preservice elementary teachers in their local communities. These include the following:

North Texas Preservice Collaborative is facilitated by the Fort Worth Museum of Science and History. Texas Christian University, the University of North Texas, Texas Wesleyan University, and Region XI Service Center will collaborate to introduce the museum as a science education arena, to provide rich informal science experiences for preservice elementary science teachers and elementary classroom teacher partners, and to develop museum-based science teaching kits.

SWT's Science Ventures into Schools is led by Southwest Texas State University in San Marcos, Texas. In this project, teacher educators are partnering with classroom teachers to experiment with a field component of a required science content course. The field experience is providing a one-hour after school Science Academy taught by preservice teachers.

Partners in Science is led by West Texas A&M University in Amarillo, Texas. In this collaborative with three junior colleges, freshmen and sophomore science students are partnering with elementary science teachers and people in industry. The project is intended to give prospective elementary teachers an opportunity to interact with the science community and to become familiar with the elementary classroom environment, as well as increase their science content knowledge.

Texarkana Preservice Science Improvement Project is headed by Texarkana College. This collaborative with a university and two school districts is focusing its energies on improved science content courses. College science faculty, elementary classroom teachers, and preservice teachers are developing and testing innovative curriculum materials for required content courses in the elementary education preparation program.

Preparation Project, defined by Howard Payne University in Brownwood, Texas, joins college faculty with teachers in Bangs ISD, Brownwood ISD, and Early ISD to restructure science content courses for preservice teachers, provide professional development experiences for classroom teachers, and increase the number of hours for elementary classroom-based experiences for preservice teachers.

Preservice Science Partners is headed by Blinn College in Bryan, Texas. Partners include Texas A&M University, the Brazos Valley Museum of Natural History, and Bryan ISD to design and lead a unique summer course in entomology designed to strengthen science content knowledge and enhance child-centered teaching experiences for both preservice and inservice teachers.

Science Teacher Training Collaborative is led by the University of Texas at Dallas. This collaborative with Texas Women's University and the University of North Texas, Region

XI Service Center and five school districts will link science content instruction in geology and ecology with intensive summer science experiences in excavating a dinosaur.

Conclusions

The three-tiered agenda of the Texas SSI is mirrored in the work of its Preservice Elementary Science Preparation (PESP) Action Team. Real and ideal states of the state in the science preparation of preservice teachers have been researched and documented. The action team developed the *Guidelines* and built consensus through a process of presentation and review. Research was conducted to confirm the current state of the state and to guide the establishment of priorities in strengthening existing programs. Currently the Texas SSI supports seven funded projects and a new action team led by the directors of those projects. A newsletter and eventual web site will support ongoing communication with elementary science teacher educators regarding continuing developments in these innovative project experiences. The release of a CD-ROM is projected for September of 1998. This product will define the uniqueness of each implementation site; present the documents, including course syllabi, developed at the site; provide videotaped interviews with project partners; and allow new insights into strategies used at the local level to implement the *Guidelines*.

The *Guidelines* are the bridge that connects the vision of reform to all other parts of the system. The three-tiered strategy of the Texas SSI provides a focus to the process of reform. In the Texas case, the plan for change in preservice elementary science preparation has been thoroughly executed through the tasks of the PESP Action Team. The team has guided all stages of the process, through the simultaneous development of *Guidelines* and implementation of well-designed research studies; through the provision of financial and organizational support for local communities in their first steps towards changing traditional preparation programs; and through the establishment of a systemic infrastructure of networking and dissemination. Careful, thoughtful planning has helped to launch the vision, build capacity, and support the establishment of communication links. Our experience in Texas has indeed indicated successful first steps towards changing the science preparation of elementary teachers, linking the complexity of stakeholders to a cohesive vision of systemic change.

Endnotes

[1]Julie A. Thomas and Carol L. Stuessy, *"Directing Change: Guiding Reform in Elementary Science Education in Texas,"* Paper Presented at the Annual Meeting, Association for the Education of Teachers of Science, Minneapolis, 1998.

[2]Bill Aldridge, "Science Education: Federal, State and Local Responsibilities for Reform," *Position Paper Prepared for the National Science Teachers' Association* (Washington, NSTA, 1991); K. R. Mechling and D. L. Oliver, "The 4th r: Stepchild of the Elementary Curriculum," *Principal* 62 (1983): 41-43; S. A. Raizen and A. M. Michelson, *The Future of Science in Elementary Schools: Educating Prospective Teachers* (San Francisco, Jossey-Bass, 1993); J. Shymansky and W. Kyle, "Overview: Science Curriculum Reform," *Journal of Research in Science Teaching* 29 (1992): 745-778.

[3]C. S. Dweck, "Motivational Processes Affecting Learning," *American Psychologist* 41: 1040-1048; Julie A. Thomas and Jon Pedersen, "Draw-A-Science-Teacher-Test: A Visualization of Beliefs and Self-Efficacy," Paper Presented at the Annual Meeting, Association for the Education of Teachers of Science, Minneapolis, 1998.

[4]Dweck.

[5]National Science Foundation, *The Learning Curve: What We Are Discovering about U. S. Science and Mathematics Education* (Washington: NSF, 1996).

[6]National Science Foundation, *Foundations: The Challenge and Promise of K-8 Science Education Reform* (Washington: NSF, 1997).

[7]James C. Collins, Director of Science Education, Texas Education Agency, personal communication, 1997.

[8]David Hill, "Organization of the Texas Statewide Systemic Initiative," Conference Keynote at Building Partnerships for Elementary Science Preparation: An Invitation, Fort Worth, TX, 1997.

[9]Hill.

[10]Dawn Parker, "Preservice Elementary Science Survey: A Description of Programs at Colleges and Universities in Texas," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996).

[11]Andrea Foster, "Interviews of Elementary Science Presidential Awardees: Patterns that Portray Excellence in Science Teaching," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, Sept. 1996).

[12]James McNamara, Dawn Parker, and Carol Stuessy, "Perspectives and Practices of Elementary Teachers about Teaching Science," Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center (Austin, in preparation).

References

Aldridge, Bill. "Science Education: Federal, State and Local Responsibilities for Reform." *Position Paper Prepared for the National Science Teachers' Association.* Washington: NSTA, 1991.

American Association for the Advancement of Science. *Benchmarks for Science Literacy.* NewYork: Oxford UP, 1993.

American Association for the Advancement of Science. *The Liberal Art of Science: Agenda for Action.* Washington: AAAS, 1990.

American Association for the Advancement of Science. *Science for All Americans.* Washington: AAAS, 1989.

Arons, A. B. "What Science Should We Teach?" *Proceedings of Curriculum Development for the Year 2000: A BSCS Thirtieth Year Symposium.* Colorado Springs: BSCS, 1989.

Berliner, David C. "In Pursuit of the Expert Pedagogue." *Educational Researcher* 43.5 (1986): 5-13.

Brooks, Jacqueline, and Martin Brooks. *In Search of Understanding: The Case for Constructivist Classrooms.* Alexandria: Association for Supervision and Curriculum Development, 1993.

Bybee, Rodger W. *Reforming Science Education: Social Perspectives and Personal Reflections.* New York: Teachers College Press, 1993.

California State Board of Education. *Science Framework for California Public Schools Kindergarten through Grade Twelve.* Sacramento: CSBE, 1990.

Clark, William C. "Managing Planet Earth." *Readings from Scientific American: Managing Planet Earth.* New York: Freeman, 1990.

Close, D., J. Miller, L. Titterington, and D. Westwood. "National Standards and Benchmarks in Science Education: A Primer." *ERIC Clearinghouse for Science, Mathematics, and Environmental Education Digest*, Dec. 1996.

Collins, James C. "Texas Essential Knowledge and Skills in Science." Paper Presented at the Annual Meeting, Conference for the Advancement of Science Teaching. Fort Worth, TX, Oct. 1997.

Cory, S. M. *Action Research to Improve School Practices.* New York: Teachers College Press,1953.

Dadyov, V. "The Influence of L. S. Vygotsky on Education, Theory, Research, and Practice." *Educational Researcher* 24.3 (1995): 17.

Dewey, John. *How We Think.* New York: Prometheus Books, 1991.

Dweck, Carol S. "Motivational Processes Affecting Learning," *American Psychologist* 41.10 (1986): 1040-1048.

Educational Research Service. *Improving Student Achievement in Science.* Arlington, VA: ERS, 1996.

Foster, Andrea. "Interviews of Elementary Science Presidential Awardees: Patterns that Portray Excellence in Science Teaching." Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center, Austin, Sept. 1996.

Foster, Andrea. "Field Notes of Interviews of Elementary Science Presidential Awardees," 1996.

Hargreaves, A., and M. Fullan. *Understanding Teacher Development.* London: Cassell, 1991.

Harms, N.C., and Yager, R.E. (Eds.). *What Research Says to the Science Teacher, Vol. 3.* Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education, 1980.

Hawkins, S., and A. M. Michelsohn. *The Preparation of Elementary School Teachers in Science: Reporting on 142 Preservice Programs.* Andover, MA: National Center for Improving Science Education, 1995.

Hill, David S. "Organization of the Texas Statewide Systemic Initiative." Conference Keynote, Building Partnerships for Elementary Science Preparation: An Invitation. Fort Worth, TX, 1997.

Hord, Shirley. "Distinguishing between Cooperation and Collaboration: A Case Study Approach to Understanding Their Relative Requirements and Outcomes." Paper Presented at the Annual Meeting, American Educational Research Association. Boston, 1980.

Hounshell, P. H. "Elementary Science Specialists?" *Science and Children* 24 (1987): 20-21, 157.

Hoyt, K. A. *A Concept of Collaboration in Career Education.* Washington: U. S. Office of Education, 1978.

Intrilligator, B. A. "Evaluating Inter-Organizational Relationships." Paper Presented at the Annual Meeting, American Educational Research Association. Montreal, 1983.

Johnston, Sue. "Experience Is the Best Teacher, Or Is It? An Analysis of the Role of Experienc in Learning to Teach." *Journal of Teacher Education* 45 (1994): 203.

Jonassen, David. *Computers in the Classroom: Mindtools for Critical Thinking.* Columbus, OH: Prentice-Hall, 1996.

Kennedy, M. M. *An Agenda for Research on Teacher Learning: A Special Report.* East Lansing, MI: Michigan State University, 1996.

Kirwan, William E. "Keynote Address: Role of Faculty in the Disciplines in Undergraduate Education of Future Teachers." *Proceedings of the National Science Foundation Workshop on The Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers.* Washington: NSF, 1993.

Kubota, Carol A., and R. G. Olstad. "Effects of Novelty Reducing Preparation of Exploratory Behavior and Cognitive Learning in a Science Museum Setting." *Journal of Research in Science Teaching* 28 (1991): 225-234.

Lanier, J. "Collaboration Session, Discussant Remarks." *Exploring Issues in Teacher Education: Questions for Future Research.* Eds. G. E. Hall, S. M. Hord, and G. Brown. Austin: Research and Development Center for Teacher Education, University of Texas, 1979.

Lederman, Norman, and M. Druger. "Classroom Factors related to Change in Students' Conceptions of the Nature of Science." *Journal of Research in Science Teaching* 22 (1985): 649-662.

Lederman, Norman, and C. L. Zeidler. "Science Teachers' Conceptions of Science: Do They Really Influence Teaching Behavior?" *Science Education* 71 (1987): 721-734.

Leven, H. M. "Accelerated Visions." *Accelerated Schools 5* (1996, Spring): 2-3.

Lieberman, Ann. "Collaborative Work." *Educational Researcher* 43.5 (1986): 5.

Loucks-Horsley, S., R. Kapitan, M. Carlson, P. Kuerbis, R. Clark, G. Marge Nelle, T. Sachse, and W. Walton. *Elementary School Science for the 90's.* Massachusetts: The Network, 1990.

Margerum-Leys, Jon. "Making Sense of the World Wide Web." Paper Presented at the Annual Meeting, School Science and Mathematics Association. Milwaukee, WI, Nov. 1997.

McNamara, James, Dawn Parker, and Carol L. Stuessy. "Perspectives and Practices of Texas Elementary Teachers about Teaching Science." Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center, Austin, in prep.

Mechling, Kenneth R., and Donna L. Oliver. "The 4th R: Science, Stepchild of the Elementary Curriculum." *Principal* 62 (1983): 41-43.

Miel, A. *Cooperative Procedures in Learning.* New York: Teachers College Press, 1952.

Mittlefehldt, B. "Changing Priorities in Elementary Science." *Curriculum Review* 24 (1985): 24, 67-69.

Munby, H., and T. Russell. "Educating the Reflective Teacher: An Essay Review of Two Books by Donald Schon." *Journal of Curriculum Studies* 21 (1989): 71-80.

National Assessment Governing Board. *Science Framework for the 1996 National Assessment of Education Progress: NAEP Science Consensus Report.* Washington: NAGB, 1996.

National Research Council. *From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology.* Washington: National Academy Press, 1996.

National Research Council. *National Science Education Standards.* Washington: National Academy Press, 1996.

National Research Council. *Science Teaching Reconsidered: A Handbook.* Washington: National Academy Press, 1997.

National Research Council and National Science Foundation. *Options for Action: Roles of Departments of Science in Teacher Preparation, Proceedings of the NRC/NSF Regional Symposium on Science, Mathematics, Engineering, and Technology Education, Johnson Space Center, Houston.* Washington: National Academy Press, 1996.

National Science Foundation. *Foundations: The Challenge and Promise of K-8 Science Education Reform.* Washington: NSF, 1996.

National Science Foundation. *The Learning Curve: What We Are Discovering about U.S. Science and Mathematics Education.* Washington: NSF, 1996.

National Science Foundation. *Proceedings of the National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers.* Washington: NSF, 1993.

National Science Foundation. *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology.* Washington: NSF, 1996.

Parker, Dawn. "Collaborative Models for Preservice Elementary Science Preparation at Colleges and Universities in Texas." Ph.D. Dissertation, Texas A & M University, College Station, Aug. 1997.

Parker, Dawn. "Preservice Elementary Science Survey: A Description of Programs at Colleges and Universities in Texas." Report Prepared for the Texas Statewide Systemic Initiative, Charles A. Dana Center, Austin, Sept. 1996.

Parsons, Sharon, and Karen E. Reynolds. "Establishing An Action Research Agenda for Preservice and Inservice Elementary Teacher Collaboration on Self-Empowerment in Science." Paper Presented at the Annual Meeting, National Association for Research in Science Teaching. San Francisco, 1995.

Phenix, Philip L. *Realms of Meaning: A Philosophy of the Curriculum for General Education.* New York: McGraw-Hill, 1964.

Raizen, Senta A., and Edward D. Britton. *Bold Ventures: Patterns Among Innovations in Science and Mathematics Education*, Vol. 1. Boston: Kluwer Academic, 1997.

Raizen, Senta A., and Arie M. Michelsohn. *The Future of Science in Elementary Schools: Educating Prospective Teachers.* San Francisco: Jossey-Bass, 1993.

Riggs, Iris M., and Larry G. Enochs. "Towards the Development of an Elementary Teacher's Science Teaching Efficacy Belief Instrument." *Science Education* 74.6 (1990): 625-637.

Scientific American. Special edition, March 1996.

Senge, Peter. *The Fifth Discipline.* New York: Doubleday, 1990.

Senge, Peter. *The Fifth Discipline Fieldbook: Strategies and Tools for Building A Learning Organization*. New York: Doubleday, 1994.

Seymour, Elaine, and Nancy M. Hewitt. *Talking About Leaving: Why Undergraduates Leave the Sciences*. Boulder: Westview Press, 1997.

Shulman, Lee. "Those Who Understand: Knowledge Growth in Teaching." *Educational Researcher* 15.2 (1986): 4-14.

Shymansky, J., and W. Kyle. "Overview: Science Curriculum Reform." *Journal of Research in Science Teaching* 29 (1992): 745-778.

Slick, Gloria Appelt. *The Field Experience: Creating Successful Programs for New Teachers*. Thousand Oaks: Corwin Press, 1995.

Slick, Gloria Appelt, and Kenneth Burrett. *Emerging Trends in Teacher Preparation: The Future of Field Experiences*. Thousand Oaks: Corwin Press, 1995.

Smith, Deborah C., and Daniel C. Neale. "The Construction of Subject-Matter Knowledge in Primary Science Teaching." *Advances in Research on Teaching* 2 (1991): 187-243.

Stevens, Carol, and George Wenner. "Elementary Preservice Teachers' Knowledge and Beliefs Regarding Science and Mathematics." *School Science and Mathematics* 96.1 (1996): 8-14.

Stuessy, Carol L., and Bruce M. Payne. *Coordinated Thematic Science II*. Austin: Texas Education Agency, 1994.

Stuessy, Carol L. "A Challenge: Employing a Model for Preservice Teacher Preparation to the Teaching and Learning of Science by Non-Science Undergraduate Students." *Proceedings of the National Science Foundation Workshop on the Role of Faculty from the Scientific Disciplines in the Undergraduate Education of Future Science and Mathematics Teachers*. Washington: NSF, 1993.

Texas SSI Preservice Elementary Science Action Team. "Goal of Elementary Science Teacher Preparation." Action Team Minutes, 16 Feb. 1996.

Texas Education Agency. *Learner-Centered Schools for Texas: A Vision of Texas Educators*. Austin: TEA, 1995.

Texas Education Agency. *Texas Essential Knowledge and Skills in Science*. Austin: TEA, Sept. 1996.

Thomas, Julie A., and Jon Pedersen. "Draw-A-Science-Teacher-Test: A Visualization of Beliefs and Self-Efficacy." Paper Presented at the Annual Meeting, Association for the Educators of Teachers of Science. Minneapolis, 1998.

Thomas, Julie A., and Carol L. Stuessy. "Directing Change: Guiding Reform in Elementary Science Education in Texas." Paper Presented at the Annual Meeting, Association for the Education of Teachers of Science. Minneapolis, 1998.

Tilgner, Peggy. "Avoiding Science in Elementary School." *Science Education* 74 (1990): 409-412.

Tobias, Sheila. *Revitalizing Undergrduate Science: Why Some Things Work and Most Don't.* Tucson: Research Corporation, 1992.

Tobias, Sheila. *They're Not Dumb, They're Different: Stalking the Second Tier.* Tucson: Research Corporation, 1990.

Tobin, Kenneth G. "Learning How To Teach Science." *Effective Interaction of Science Teachers, Researchers, and Teacher Educators, Monograph 1,* Southern Association for the Education of Teachers of Science Series, 1991.

Treisman, Uri. "Mid-Point Report: Texas Statewide Systemic Initiative. Report prepared for the National Science Foundation." Austin: Charles A. Dana Center, Dec. 1995.

Watson, Kieran. "Verbal Exams Force Understanding." *The Battalion* 4.18 (1996): 5.

Wiseman, Donna, and Donna Cooner. "Discovering the Power of Collaboration: The Impact of a School-University Partnership in Teaching." *Teacher Education and Practice* 12.1 (1996): 18-28.

Yager, Robert, Martha V. Lutz, and John A. Craven III. "Do National Standards Indicate the Need for Reform in Science Teacher Education?" *Journal of Science Teacher Education* 7.2 (1996): 88.

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